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THE

JOURNAL

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

CONTAINING
THE PROCEEDINGS

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS 29 W. 39 ST. N.Y.

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MARCH 1909 VOL. 31 No. 3

THE JOURNAL
OF
THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

PUBLISHED AT 2427 YORK ROAD - - - - BALTIMORE, MD.
EDITORIAL ROOMS, 29 W. 39TH STREET - - - - NEW YORK

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The Journal is published by The American Society of Mechanical Engineers twelve times a year, monthly except in July and August, semi-monthly in October and November.
Price, one dollar per copy—fifty cents per copy to members. Yearly subscription, $7.50; to members, $5.
Application filed for entry at the Postoffice, Baltimore, Md., as second-class mail matter under the act of March 3, 1879

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The professional papers contained in The Journal are published prior to the meetings at which they are to be presented, in order to afford members an opportunity to prepare any discussion which they may wish to present.

The Society as a body is not responsible for the statements of facts or opinion advanced in papers or discussions. C55.

TESTS UPON COMPRESSED AIR PUMPING SYSTEMS OF OIL WELLS

By Edmund M. Ivens, New Orleans, La.

Junior Member of the Society

When the Louisiana oil fields at Evangeline were in full operation, they offered exceptional opportunities for the study of air lifts. Nearly every known method of piping the wells was in use. The air plants originally installed were the crudest affairs imaginable, having been erected in feverish haste during the boom several years ago. When the production of the fields began to decrease, and the price of oil also declined, it was realized for the first time that the operating expenses were abnormal, and that unless greater economy were practiced, disastrous results would follow. Few changes were made, however, up to eighteen months ago, beyond the purchasing of additional equipment.

2 Each concern has a central station or air plant and all the compressors therein are connected to a manifold from which the air lines lead to the various wells on the property held by that concern. The manifold design is such that by manipulating the valves, any machine may be made to operate any of the wells.

3 Often the air lines reach the wells by a roundabout way, and have innumerable short bends, valves, double swings to avoid pipe cutting, and plugged tees instead of elbows. All of this tends further to decrease the economy of the operation, and taking all things into consideration, it is little wonder that the efficiencies of the plants were low. The size pipe used for these air lines is designed neither for the amount of air to be transmitted nor for the distance it is to be carried, but is with one exception 2 in. in diameter.

4 The boilers of the air plants are of 40 h.p., of a portable contracted waist type, and few were covered with asbestos. The boilers were so set that one-fifth of their lengths projected into the open, as

To be presented at the Spring Meeting of The American Society of Mechanical Engineers. All papers are subject to revision.

indicated in Fig. 1, in order to avoid the necessity of perforating the roof to receive the stacks and to provide cooler boiler-rooms, regardless of the heat wasted.

5 The redeeming feature in all the plants is the type of compressor in general use. These compressors are generally of high grade, and display remarkable endurance. It is common for a machine designed for 350-lb. pressure to operate under a pressure of 500 lb., and at speeds far in excess of those for which it was designed. The most popular type of compressor has the duplex steam end and compound or two-stage air end. The steam cylinders are fitted with Meyer adjustable cut-off valves and the air cylinders in some instances with piston and in others with Corliss intake valves and poppet discharge valves. Plain speed governors are used and the capacities of the

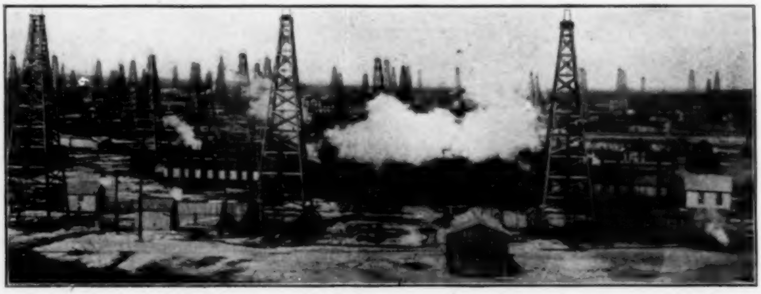


FIG. 1 A TYPICAL AIR PLANT

compressors range from 100 to 1000 cu. ft. of free air per minute and operate at pressures of from 150 to 750 lb. per square inch. The machine best adapted to the purpose, however, is the 500 cu. ft., 500-lb. type.

TERMS

6 An explanation of certain terms to be used may not be out of place.

"Submergence in feet" refers to the number of feet below the surface of the fluid (after the well has been pumped down, and is operating under its normal conditions) that the air under pressure is admitted.

"Per cent of submergence" is the submergence in feet divided by the total number of feet of vertical discharge line, measured from the point of admission of the air to the point of discharge of the fluid.

"Volumetric efficiency" of the compressor is the actual amount of free air that is compressed and discharged by the cylinder, divided by the cubical contents of that cylinder.

"Free air" is air at standard temperature and pressure.

"Pumping head" is the vertical distance in feet (after the well is pumped down, as before stated) from the fluid level in the well to the point of discharge.

$$\text{"The Constant"} = \frac{\text{Gal. per minute} \times \text{pumping head in feet}}{\text{Cu. ft. of free air per minute}}$$

$$\text{"The Ratio"} = \frac{\text{Cu. ft. of free air per minute}}{\text{Cu. ft. of fluid per minute}}$$

DESCRIPTION OF SYSTEMS

7 Fig. 2, 3, 4, and 5, illustrate the air lift systems that are and have been in use on the oil fields.

8 Fig. 2 shows the Straight Air or Sanders system. The well top is sealed as shown at A. Compressed air is forced through the pipe B into the space between the discharge or eduction pipe C, and the well casing D.

9 When without air pressure the fluid in the well will stand at some point such as E, the level in the air space and the discharge line being identical. When air is forced through B, the level of the fluid in the air space is gradually forced down until the end of C is uncovered. Instantly some of the air escapes into the discharge pipe C, lowering the air pressure in the air space F. This causes the fluid to rise in and up the air space and discharge pipe until a point is reached where air and water pressure balance. Then, more air coming in, the pressure again rises, the fluid level is forced down as before, more air escapes into the discharge pipe, and thus the cycle is repeated. As may be readily seen, the air that rushes into the discharge line carries the "slug" of water that has just previously entered.

10 Fig. 3 shows what is commonly known as the Central Pipe system. The discharge line A is placed inside of the well casing as before and inside of the discharge is suspended a small air line usually $1\frac{1}{4}$ in. in diameter. The end of the $1\frac{1}{4}$ in. line is plugged and a number of $\frac{1}{8}$ in. holes are drilled inclining upwards in the last joint of pipe. Air is forced down through the small air line shown, passes out of the $\frac{1}{8}$-in. holes, and mingles with the fluid carrying it out through the discharge line A. It is generally supposed that the fluid in this

case is discharged because of the aëration of the fluid in the discharge pipe which in turn is caused by the intimate commingling of air and fluid. The weight of the fluid column inside of the discharge pipe is therefore less in pounds per square inch than that without and the energy due to this difference in weight is utilized to lift the fluid and overcome the various losses.

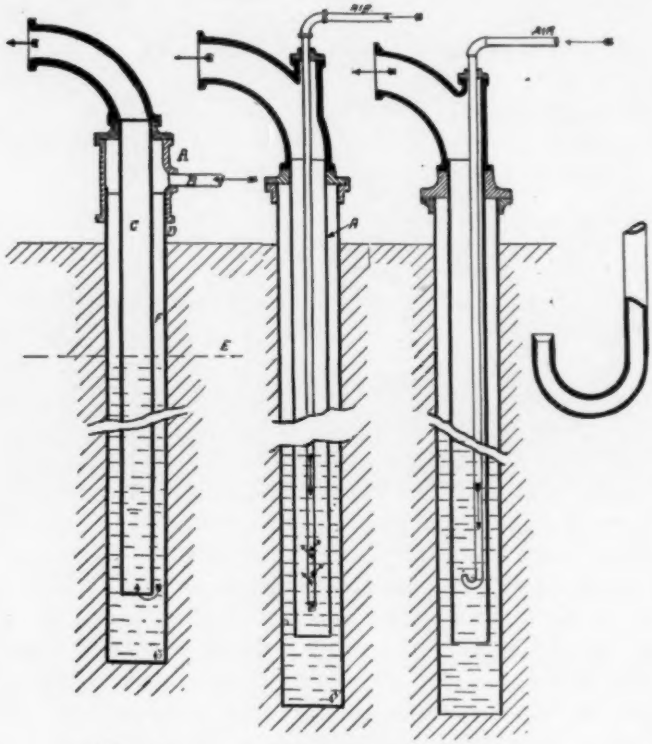


Fig. 2 STRAIGHT AIR LIFT SYSTEM — Fig. 3 CENTRAL PIPE SYSTEM — Fig. 4 RETURN BEND SYSTEM

11 What is commonly known as the Open End system of air lift was at one time in quite extensive use on the field. It is similar to the system just described except that the small air line is open at the lower end, and of course there are no holes drilled in the air line.

12 Fig. 4 illustrates a form of the Return Bend system. It is claimed by the inventor that: "It consists in improved processes and

apparatus whereby the compressed air is delivered in bulk into the lower end of the water eduction pipe, and the water and air are caused to ascend through said pipe in distinct alternate layers of definite dimensions."

13 The use of this system has been discontinued in Evangeline because, as the field managers told the writer, it failed to produce as large a quantity of fluid as that produced by other systems.

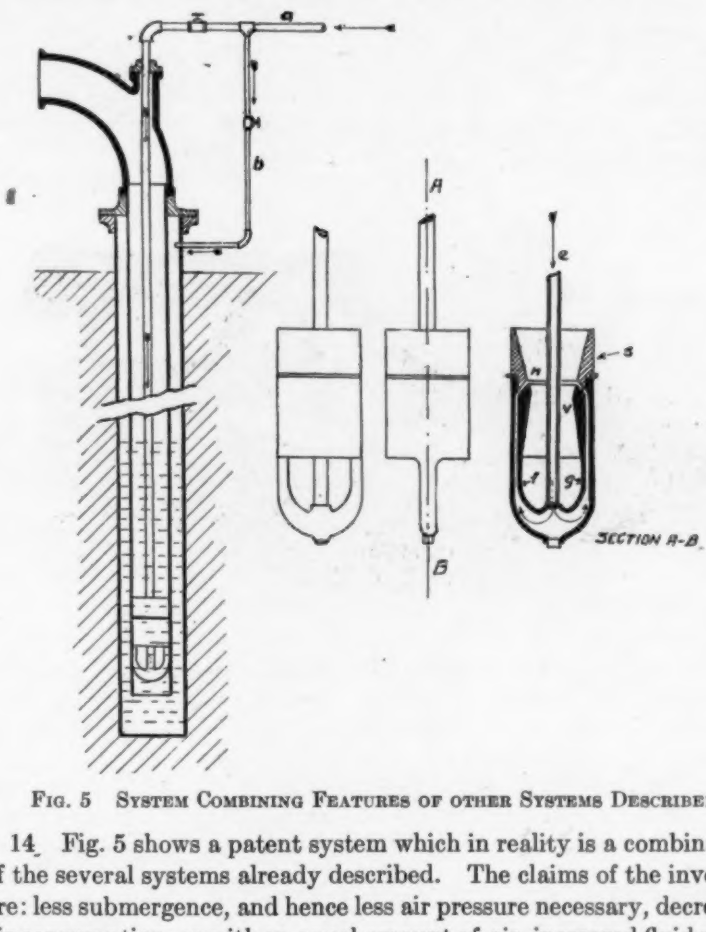


FIG. 5 SYSTEM COMBINING FEATURES OF OTHER SYSTEMS DESCRIBED

14 Fig. 5 shows a patent system which in reality is a combination of the several systems already described. The claims of the inventor are: less submergence, and hence less air pressure necessary, decreased air consumption, or with an equal amount of air, increased fluid yield.

15 Compressed air is forced through *a* down into the foot piece, which is placed at that point of submergence shown by test to be most economical. The well top is sealed and air under pressure

is also admitted between the casing and discharge pipe on the water head by means of the branch shown at *b*. This forces the fluid to a higher level in the discharge pipe and also prevents fluid in the air space or chamber from vibrating and foaming. This is quite an advantage in oil well pumping as the liability of making "riley oil" is thereby greatly lessened.

16 The footpiece shown in section is made of cast brass and is in two parts. The air on reaching the foot piece divides and goes up through the hollow prongs *f* and *g* and out the nozzle *n*. The nozzle is adjusted to receive the quantity of air to be used by screwing the upper part *s* of the footpiece, in or out as the case may be. To increase the velocity of the fluid in the discharge line, the footpiece is restricted and formed into a "venturi" as shown at *v*.

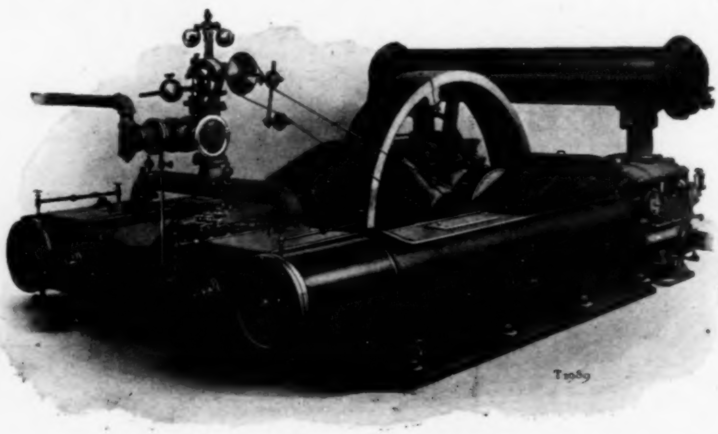


Fig. 6 Type of Compressor Used

Test No. 1

17 The Crowley Oil and Mineral Company was the first to take active steps for the improvement of their plant and pumping equipment. They decided to install the patent air lift last described (Fig. 5). A test of the old system was first made to determine the amount of compressed air used and the fluid yield. The new equipment was next installed and a similar test made of the same duration and under the same conditions. The tests and installation were conducted on Well No. 32, 1805 ft. deep, and located 542 ft. from the compressor operating it. The air to the well was controlled by means

of a manifold in the plant and was conveyed to the well top through a two-in. pipe line which as usual was in poor condition and badly designed.

18 The system of pumping was that illustrated in Fig. 2. The well casing was 6 in. in diameter, suspended inside of which was a 4-in. discharge line.

19 The compressor was a duplex steam and compound air type made by the Ingersoll-Rand Company and designed to compress 1000 cu. ft. of free air per minute to 350 lb. pressure. The steam end was fitted with Meyer adjustable cut-off valves and the air end with Corliss intake and poppet discharge valves. The machine is shown in Fig. 6.

20 The discharge pipe from the well top was run up into a steel tank of known dimensions and the amount of fluid pumped during the

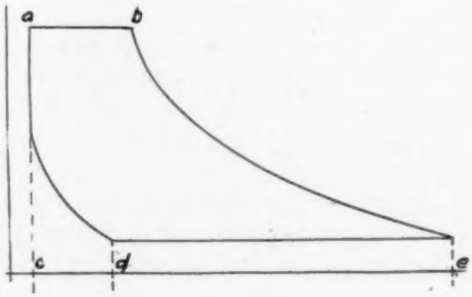


Fig. 7

test ascertained by direct measurement. Air gages, previously tested, were placed both at the compressor and at the well top thereby making it possible to determine the friction losses in the manifold and air line and also the actual pressure at the well top. Simultaneous indicator cards were taken from the steam and air ends of the compressor, and from these cards were obtained the volumetric and mechanical efficiencies, the steam and air horse powers, and the steam consumption (theoretical) of the machine.

21 The volumetric efficiency was assumed to be the ratio of the total piston displacement to the dsplacement at the point where the admission valve opens, ($\frac{de}{ce}$ on the indicator card, Fig. 7). Sometimes this method is inaccurate and unsatisfactory (1) because the entering air at atmospheric temperature and pressure is heated by

contact with the cylinder walls and piston; and (2) because of leakage of air from the compression side of the moving piston to the suction side. Neither the expansion resulting from the first condition nor the reduction in volumetric efficiency resulting from the second are observable on the indicator card.

22 The first inaccuracy was partially overcome by placing a recently calibrated thermometer as far down in the intake pipe of the compressor as possible, noting the temperature and making the necessary corrections as will be observed in the log of results.

23 The method of ascertaining the volumetric efficiency, that the writer would have used, but for his inability to obtain the necessary apparatus, was in brief as follows:

Connect the air discharge of the compressor to an enclosed tank. From this tank, connect to a cooler and from thence to a second enclosed tank of known dimensions.

Place a regulating valve between the first tank and the cooler, setting the valve to maintain the pressure in the first tank at that point at which the efficiency is to be determined.

Attach test gages to both tanks and a reliable thermometer to the second tank.

Start the compressor and note the temperatures of the intake air and of the air in the second tank both at the beginning and end of the run. Note also the initial and final air pressures and the reading of the barometer, and the speed in revolutions per minute of the compressor.

The volume of air compressed is then determined from the formula:

$$V = v\,\frac{273 + T}{R}\left(\frac{29.92 \times P_1}{273 + T_2} - \frac{29.92 \times P}{273 + T_1}\right)$$

where

V = Volume of air compressed.
v_1 = Cubical contents of the second tank.
T = Room, or intake air, temperature.
T_1 = Initial temperature of the air in the tank.
T_2 = Final temperature of the air in the tank.
R = Reading of the barometer in inches of mercury.
P and P_1 = Initial and final air pressures in the tank.

The volume of air thus obtained divided by the total piston displacement equals the volumetric efficiency.

OBSERVATIONS

24 Every thirty minutes for a period of six hours, readings were taken of the boiler pressure gage, the air gage at the compressor and at the well top, the r.p.m. of the compressor, the temperature of the intake air and of the barometer. A set of indicator cards, and also a sample of the fluid pumped from the well, were taken at each interval.

25 The temperature of each sample of fluid was noted; it was then placed in a proper receptacle, and at the end of the test, the weight of a gallon was ascertained, together with the specific gravity of the oil. The amount of fluid pumped was determined, as before stated, by direct measurement, due allowance having been made for the samples that were withdrawn.

26 When these tests were run, no attempt was made by the writer to re-design the air lines, or to correct in any manner the numerous other defects. The old system was tested just as it had been operated, and the new system was installed and tested under the same adverse conditions. After both systems had been tested, some few of the defects were corrected in the manifold and air line design, thereby insuring more economical operation in the future.

TABLE 1 SUMMARY OF RESULTS

The Crowley Oil and Mineral Company, Evangeline, La.

	Old System	New System
Duration of test, hours	5.5	6.0
Mean i.h.p.	122.56	89.19
Mean water h.p.	9.97	10.36
Mean air h.p.	107.38	79.16
Gallons of fluid per second	0.542	0.608
" " " hour	1953.6	2188.2
Barrels of fluid per hour	46.51	52.1
Weight of 1 gal. of fluid	8.7	8.69
Mean temperature of fluid, deg. fahr.	111.5	113.2
Percentage of salt water in fluid	87.3	86.7
" " sand "	2.2	1.9
" " crude oil "	10.5	11.4
Barrels of oil per hour	4.86	5.94
Barometer reading, inches of mercury	29.95	29.94
Specific gravity of oil	0.9	0.9

	Old System	New System
Constant	63.1	101.8
Size of air line, inches		1.25
Total depth of well, feet	1805.0	1805.0
Size of casing, inches	6.0	6.0
Height above ground to which the fluid was pumped, feet	18.5	18.5
Size of discharge line used, inches	4	4
Total length of vertical discharge line	1513.5	1513.5
Total length of vertical air line in well	1513.5	1493.0
Dimensions of compressors, inches*	10x22x16x20–	7½x18x16x20
Number operated	1	1
Kind of fuel used†	Crude oil	Crude oil
Gallons of fuel used per hour	48.36	35.27
Barrels of fuel used per hour	1.15	0.835
Price of 1 bbl. of oil at time of test, dollars	0.90	0.90
Cost of fuel for producing 1 bbl. of fluid, dollars	0.0222	0.0146
Cost of fuel for producing 1 bbl. of crude oil, dollars	0.212	0.126

*Type of compressor used, Rand Drill Co. Imperial Type X, Steam Cylinders, compound air cylinders.

†Type of boiler, oil well supply, portable contracted waste.

Test No. 2

WELLS NO. 12, 30, AND 32 OF THE CROWLEY OIL AND MINERAL COMPANY

27 The saving in air volume accomplished by the new system led those interested to endeavor to operate two wells with one machine, something before considered impossible in the field.

28 Well No. 30 was forthwith tested, though not with sufficient accuracy to warrant the publication of the results, and the approximate pumping head and submergence established. The new system was then installed with the requisite pipe to equalize the submergence (hence working pressure) of this well with that of No. 32. How successfully the working pressures of the two wells were equalized may be seen by reference to Table 2 of the Appendix.

29 The two wells in question were then connected to one air compressor with gratifying results. No trouble was experienced in starting, and the machine furnished air in abundance for steady operation.

30 Preparations were being made to run the usual test when the compressor operating Well No. 12 "went dead." This last named well had been previously tested and equipped with the new system. This shutdown, of course, would mean a loss of at least a day's pro-

duction from the well, amounting to quite an item, so the writer advised that this well be also connected to the machine already operating No. 30 and No. 32. By speeding the machine up a few revolutions, the additional load was easily taken care of as may be more fully noted by reference to the accompanying log (Table 2).

TABLE 2 SUMMARY OF RESULTS

WELLS NO. 12, 30, 32, CROWLEY OIL AND MINERAL COMPANY

Duration of tests, hours	6.0
Mean (total) i.h.p.	151.1
" " w.h.p.	25.14
" " a.h.p.	129.05
Total gallons of fluid per hour	6168.0
" barrels " " " "	146.87
" " " oil " "	16.17

WELL NO. 12

Weight of 1 gal. of fluid	8.5
Temperature of fluid	118.5
Per cent of salt water in fluid	87.2
" " " sand " "	1.3
" " " crude oil " "	11.5
Barrels of oil per hour	6.44
Specific gravity of oil	0.87
Total depth of well in feet	1705.00
Size of casing, inches	6.00
" " discharge line, inches	4.00

WELL NO. 30

Height above ground to which fluid was pumped, feet	17.5
Total length of vertical discharge line	1025.5
" " " " air line	992.58
Weight of 1 gal. of fluid	8.65
Temperature of fluid	120.2
Per cent of salt water in fluid	88.3
" " " sand " "	1.5
" " " crude oil " "	10.2
Barrels of oil per hour	4.83
Specific gravity	0.9
Total depth of well in feet	1920.00
Size of casing, inches	6.00
" " discharge line, inches	4.00

Height above ground to which fluid was pumped, feet	18.00
Total length of vertical discharge line	1516.3
Total length of vertical air line in well	1494.2

WELL NO. 32

Weight of 1 gal. of fluid, pounds	8.7
Temperature of fluid	114.5
Per cent salt water in fluid	86.9
" " sand " "	1.8
" " crude oil " "	11.3
Barrels of oil per hour	4.90
Specific gravity	0.9
Total depth of well, feet	1901.00
Size of casing, inches	6.00
" " discharge "	4.00
Height above ground to which fluid was pumped	18.5
Total length of vertical discharge line	1513.0
Total length of vertical air line in well	1493.0
Size of air lines in wells, inches	1.25
Barometer reading, inches of mercury	29.95
Dimensions of compressor, inches*	10x22x16x20
Number operated	1
Kind of fuel used†	Crude oil
Barrels of fuel used per hour	1.45
Price of 1 bbl. of oil at time of test, dollars	0.90
Cost in fuel of producing 1 bbl. of oil, dollars	0.074

*Type of compressor used, Rand Drill Co. Imperial Type X, duplex steam cylinders, compound or two stage, air cylinders.

†Type of boilers, oil well supply, portable contracted waste.

TEST NO. 3

MILL HILL NO. 2, MAMOU POWER COMPANY

31 This test was run in the same manner as those preceding except that the fluid field was ascertained by means of a two-foot rectangular weir placed between the earthern fluid and oil pits, the salt water bleeds of the former having been closed. The old system used was that illustrated in Fig. 3.

32 The depth of fluid over the crest of the weir was measured by means of the ordinary hook gage calibrated to read accurately in hundredths of a centimeter. The weir constant was previously determined by testing in the usual way, using a sample of the fluid as pumped from the well.

TABLE 3 SUMMARY OF RESULTS

Well No. 2, Mamou Power Company

	Old System	New System
Duration of tests, hours	10.0	10.0
Mean i.h.p.	99.1	62.8
" w.h.p	9.85	13.36
" a.h.p	82.5	50.4
Gallons of fluid per second	0.694	0.849
" " " " hour	2499.6	3056.4
Barrels of fluid per hour	54.75	72.77
Weight of 1 gal. of fluid, pounds	8.72	8.75
Mean temperature of fluid, deg. fahr.	118.3	117.9
Percentage of salt water in fluid	87.7	86.1
" " sand " "	1.2	1.6
" " crude oil in fluid	11.1	12.3
Barrels of oil per hour	6.08	8.95
Specific gravity of oil	0.9	0.9
Barometer reading, inches of mercury	29.94	29.93
Weir constant	24.39	24.39
Pumping constant	97.1	202.9
Total depth of well in feet	1901.0	1901.0
Size of casing, inches	6.0	6.0
Height above ground to which fluid was pumped, feet	3.33	3.33
Size of discharge line used, inches	4.0	4.0
Size of air line in well, inches		1.25
Total length of vertical discharge line	1500.0	1500.0
Total length of air line in well	1489.5	1489.5
Dimensions of compressor, inches*	7½x18x16x16	7½x18x16x16
Number operated	1	1
Kind of fuel used†	Crude oil	Crude oil
Gallons of fuel used per hour	44.22	30.53
Barrels of fuel " " "	1.05	0.727
Price of 1 bbl. of oil at time of test, dollars	0.85	0.85
Cost in fuel of producing 1 bbl. of fluid, dollars	0.0163	0.0085
Cost in fuel of producing 1 bbl. of crude oil, dollars	0.128	0.069

*Type of compressor used, Hall Steam Pump Co., Duplex steam cylinders, compound air cylinders, Plain "D" valves on steam end, poppet valves on air end.

†Type of boiler, 72"x18' horizontal return tubular, manufactured by the Lockout Boiler Co.

Conclusion

33 A careful examination of the tests brings out several points that may require explanation.

34 The loss of air pressure by friction in the small 1¼-in. air line in the well, to which the footpiece of the new system was attached,

was approximately determined as follows: Pipe connections were made at the well top, so that by the manipulation of various valves, the air from the main line could be sent either through the 1¼-in. air line or into the space between the well casing and the discharge line. By noting the pressure gage readings in each instance, the friction loss (assuming that there is no loss by friction when air is forced between casing and discharge) is represented by the difference in the readings. Corrections were made, of course, for that part of the discharge line below the footpiece.

35 It was impossible to obtain the actual friction loss in said 1¼-in. line by other means more accurate than those employed. While some little error may be involved in assuming no friction loss in the one instance, a comparison of the loss thus obtained with the theoretical loss is quite favorable, the former loss being the greater.

36 Reference to Table 3 will show that the working submergence of the new system is less than that of the old, in spite of the fact that there is the same amount of pipe in the well in each case. This is due to the additional drop in pumping head caused by the increase of fluid yield. All calculations of submergence and pumping head were made from the observed air pressures after correcting for friction losses, etc. The mean of these calculations was verified as far as possible by actual measurement. This was done by shutting down the compressor after the well had been in steady operation for several hours and pulling the discharge line. The point at which the fluid stood, while the well was being pumped, was plainly defined on the pipe. The time required after shutting down the compressor to pull the first "triple" from the well was a fraction less than two minutes. Comparison of the actual pumping head and submergence thus obtained with those obtained by calculations from the pressure gage readings was in each case very close, a difference of 10 ft. 2 in. being the maximum.

37 Acknowledgment of valuable aid during tests is hereby made to the following who checked the writer in his various observations: On Well No. 32, to Mr. B. Brand, of the Crowley Oil and Mineral Co.; on Wells No. 12, 30 and 32, to Mr. Brand, Mr. J. Murphree and Mr. S. Bolin, of the Crowley Oil and Mineral Co.; on Well No. 2 of the Mamou Power Co., to Mr. J. A. Sonet of that company and his able assistants; and especially is the writer grateful to Mr. J. W. Smith for courtesies extended during the former's sojourn on the field.

APPENDIX

TABLE 1 TESTS OF WELL NO. 32

Crowley Oil and Mineral Co., Evangeline, La.

Old System, November 4, 1907

Number	Time	Cu. Ft. of Free Air per Minute (Displacement)	Volumetric Per Cent Efficiency	Temperature of Air Degrees Fahr.	Cu. Ft. of Free Air per Minute (Actual)	Fluid Level in Tank	Gallons per Minute	Cu. Ft. of Fluid per Minute	Ratio	Air Pressures			Pumping Head	I. H. P.	W. H. P.	A. H. P.	R. P. M.	Submergence in Feet	Submergence Per Cent	Pumping Efficiency Per Cent
										Discharge	Intercooler	At Well								
1	1:15	632.16	92.0	86.3	555.75	1 ft. 8¾ in.	32.56	4.35	127.7	155.0	60	150.0	1167.0	118.3	10.03	103.37	72	346.5	22.8	9.7
2	1:45	623.38	91.5	86.3	545.06	....	32.56	4.35	125.2	157.2	60	153.5	1159.82	119.1	9.98	103.6	71	353.58	23.2	9.6
3	2:15	632.16	92.0	86.3	555.75	....	32.56	4.35	127.7	155.1	60	150.0	1167.0	118.3	10.03	103.4	72	346.5	22.8	9.7
4	2:45	632.16	92.0	86.3	555.75	....	32.56	4.35	127.7	157.4	60	149.0	1169.3	118.2	10.00	102.8	72	344.19	22.6	9.8
5	3:15	667.28	90.0	86.3	573.83	....	32.56	4.35	131.9	155.0	62	152.0	1162.7	123.4	9.99	107.3	76	350.82	23.1	9.3
6	3:45	658.50	91.0	86.0	571.79	....	32.56	4.35	131.5	166.3	60	150.0	1167.0	121.2	10.03	105.4	75	346.5	22.8	9.6
7	4:15	693.62	91.0	86.0	603.51	....	32.56	4.35	138.6	166.0	61	155.0	1155.45	130.5	9.92	113.5	79	358.05	23.6	8.8
8	4:45	667.28	90.0	86.3	573.83	....		4.35	131.9	166.0	60	155.5	1054.35	135.5	9.92	117.8	76	359.15	23.7	8.3
9	5:15	658.50	91.0	86.3	571.79	....	32.56	4.35	131.5	166.4	60	155.7	1053.84	123.6	9.92	107.5	75	359.66	23.7	9.2
10	5:45	693.62	91.0	86.0	603.51	....	32.56	4.35	138.6	155.0	62	156.4	1052.22	121.2	9.92	113.5	79	361.28	23.8	8.8
11	6:15	632.16	92.0	86.3	555.75	....	32.56	4.35	127.7	160.0	60	150.0	1167.0	118.3	10.03	103.4	72	346.5	22.8	9.7
12	6:45	649.72	91.6	85.7	569.34	4 ft. 11¼ in.	32.56	4.35	130.6	163.0	60	155.0	1155.45	123.1	9.92	107.04	74	358.05	23.6	9.3

TABLE 1 TEST OF WELL No. 32—Continued

New System, November 6, 1907

Number	Time	Cu. Ft. of Free Air per Minute (Displacement)	Volumetric per Cent Efficiency	Temperature of Air Degrees Fahr.	Cu. Ft. of Free Air per Minute (Actual)	Fluid Level in Tank	Gallons per Minute	Cu. Ft. of Fluid per Minute	Ratio	Air Pressures			Pumping Head	I. H. P.	W. H. P.	A. H. P.	R. P. M.	Submergence in Feet	Submergence per Cent	Pumping Efficiency per Cent
										Discharge	Intercooler	At Well								
1	12:00	448.4	92.0	82.0	395.8	1 ft. 6 in.	36.47	4.87	81.2	207	77	202	1076.5	91.5	10.3	79.6	76	416.5	27.9	13.0
2	12:30	442.5	91.5	82.0	388.4	....	36.47	4.87	79.8	207	77	202	1076.5	89.8	10.3	78.1	75	416.5	27.9	13.2
3	1:00	436.6	90.0	82.0	377.01	....	36.47	4.87	77.5	205	77	200	1081.1	86.7	10.4	75.4	74	411.19	27.6	13.8
4	1:30	436.6	90.0	82.0	377.01	....	36.47	4.87	77.5	205	77	200	1081.1	86.7	10.4	75.4	74	411.19	27.6	13.8
5	2:00	442.5	91.5	81.3	388.9	....	36.47	4.87	79.9	205	77	200	1081.1	89.5	10.4	77.8	75	411.19	27.6	13.3
6	2:30	442.5	91.5	81.5	388.8	....	36.47	4.87	79.9	205	77	200	1081.1	89.4	10.4	77.7	75	411.19	27.6	13.3
7	3:00	448.4	92.0	81.6	396.1	....	36.47	4.87	81.4	210	77	205	1069.6	92.5	10.3	80.4	76	423.4	28.4	12.8
8	3:30	442.5	91.5	81.2	389.1	....	36.47	4.87	80.0	207	77	202	1076.5	89.9	10.3	78.7	75	416.5	27.9	13.2
9	4:00	442.5	91.5	81.3	388.9	....	36.47	4.87	79.9	210	77	205	1069.6	90.7	10.3	78.9	75	423.4	28.4	13.1
10	4:30	436.6	90.5	81.0	379.7	....	36.47	4.87	77.8	205	77	200	1081.1	87.3	10.4	75.9	74	411.9	27.6	13.7
11	5:00	436.6	91.2	81.0	382.7	....	36.47	4.87	78.6	205	77	200	1081.1	87.9	10.4	76.5	74	411.9	27.6	13.6
12	5:30	442.5	90.2	80.5	383.9	....	36.47	4.87	78.1	205	77	200	1081.1	88.5	10.4	76.8	75	411.9	27.6	13.5
13	6:00	442.5	91.0	80.5	387.4	5 ft. 1½ in.	36.47	4.87	79.5	205	77	200	1081.1	89.1	10.4	77.5	75	411.9	27.6	13.4

TABLE 2 TEST OF WELLS NO. 12, 30, AND 32

CROWLEY OIL AND MINERAL CO., NOVEMBER 13, 1907

NEW SYSTEM INSTALLED IN EACH

Number	Time	Cu. Ft. of Free Air per Minute (Displacement)	Volumetric Efficiency (Mean)	Temperature of Intake Air, Degrees Fahr.	Cu. Ft. of Free Air per Minute (Actual)	Gallons per Minute			Total Gallons per Minute	Cu. Ft. of Fluid per Minute	Ratio	Air Pressures					Gallons per Minute per 100 Cu. Ft. of Free Air	I. H. P.	W. H. P.			Total W. H. P.	R. P. M.	A. H. P.	Per Cent Submergence			Pumping Heads			Pumping Efficiency
						No. 12	No. 30	No. 32				Discharge	Intercooler	At Well No. 12	At Well No. 30	At Well No. 32			No. 12	No. 30	No. 32				No. 12	No. 30	No. 32	No. 12	No. 30	No. 32	
1	11:00	719.9	....	76.5	628.02	39.2	33.2	30.4	102.8	13.74	45.7	217	65	128	202	205	16.4	155.7	7.1	9.4	8.6	25.1	82	132.3	25.9	28.0	28.4	696.9	1077.7	1069.6	18.9
2	11:30	719.9	....	76.5	628.02	39.2	33.2	30.4	102.8	13.74	45.7	215	65	128	205	202	16.4	155.1	7.1	9.3	8.65	25.05	82	131.9	25.9	28.5	27.9	696.9	1070.8	1076.5	19.0
3	12:00	710.2	....	76.7	619.3	39.2	33.2	30.4	102.8	13.74	45.1	215	65	128	205	200	16.6	152.9	7.1	9.3	8.7	25.1	81	129.9	25.9	28.5	27.6	696.9	1070.8	1081.1	19.3
4	12:30	702.4	....	76.7	612.3	39.2	33.2	30.4	102.8	13.74	44.5	215	65	128	202	200	16.8	151.2	7.1	9.4	8.7	25.2	80	128.5	25.9	28.0	27.6	696.9	1077.7	1081.1	19.5
5	1:00	684.8	....	77.0	584.04	39.2	33.2	30.4	102.8	13.74	42.5	215	65	128	202	202	17.6	144.3	7.1	9.4	8.65	25.15	78	122.5	25.9	28.0	27.9	696.9	1077.7	1076.5	20.4
6	1:30	693.6	....	77.0	604.5	39.2	33.2	30.4	102.8	13.74	43.9	215	65	133	202	202	17.0	149.3	6.9	9.4	8.65	24.95	79	126.9	26.9	28.0	27.9	685.5	1077.7	1076.5	19.7
7	2:00	719.9	90	77.0	627.4	39.2	33.2	30.4	102.8	13.74	45.6	217	65	128	205	205	16.4	155.6	7.1	9.3	8.6	25.0	82	132.3	25.9	28.5	28.4	696.9	1070.8	1069.6	18.9
8	2:30	693.6	....	76.5	605.7	39.2	33.2	30.4	102.8	13.74	44.1	215	65	128	202	200	16.9	149.6	7.1	9.4	8.7	25.1	79	127.0	25.9	28.0	27.6	696.9	1077.7	1081.1	19.7
9	3:00	710.2	....	76.5	619.7	39.2	33.2	30.4	102.8	13.74	45.1	215	65	128	202	200	16.6	153.1	7.1	9.4	8.7	25.2	81	130.0	25.9	28.0	27.6	696.9	1077.7	1081.1	19.3
10	3:30	702.4	....	76.0	613.3	39.2	33.2	30.4	102.8	13.74	44.6	215	65	123	202	202	16.5	151.5	7.2	9.4	8.65	25.25	80	128.7	24.5	28.0	27.9	708.5	1077.7	1076.5	19.5
11	4:00	702.4	....	76.0	613.3	39.2	33.2	30.4	102.8	13.74	44.6	215	65	128	205	205	16.8	151.5	7.2	9.3	8.65	25.1	80	128.7	25.9	28.5	28.4	696.9	1070.8	1069.6	19.5
12	4:30	710.2	....	75.5	620.7	39.2	33 2	30.4	102.8	13.74	45.2	215	65	128	202	202	16.6	153.3	7.2	9.4	8.6	25.25	81	130.3	25.9	28.0	27.9	696.9	1077.7	1076.5	19.3
13	5:00	702.4	....	75.5	613.9	39.2	33.2	30.4	102.8	13.74	44.7	215	65	128	202	202	16.8	151.5	7.2	9.4	8.65	25.25	80	128.7	25.9	28.0	27.9	696.9	1077.7	1076.5	19.5

TABLE 3 TEST OF HILL NO. 2

MAMOU POWER CO., EVANGELINE, LA.

Old System, February 27, 1908

Number	Time	Cu. Ft. of Free Air per Minute (Displacement)	Volumetric Efficiency	Temperature of Air Degrees Fahr.	Cu. Ft. of Free Air per Minute (Actual)	Depth of Fluid over Weir, Cm.	Gallons per Minute	Cu. Ft. of Fluid per Minute	Ratio	Air Pressures			Pumping Head	I. H. P.	W. H. P.	A. H. P.	R. P. M.	Submergence Feet	Submergence, per Cent	Pumping Efficiency per Cent
										Discharge	Intercooler	At Well								
1	7:45	413.6	85.2	75.1	342.46	1.71	41.7	5.57	61.5	260	80	252.5	916.72	91.8	10.1	75.3	88	583.28	38.8	13.4
2	8:45	441.8	84.7	77.5	362.04	1.72	41.95	5.61	64.5	260	80	252.5	916.72	93.3	10.2	75.3	94	583.28	38.8	13.5
3	9:45	498.2	85.0	77.8	409.51	1.71	41.7	5.57	73.4	255	80	247.4	866.14	108.9	9.6	89.4	106	633.86	42.3	10.7
4	10:45	470.0	85.0	78.2	386.01	1.70	41.46	5.54	68.5	255	80	247.4	866.14	98.8	9.5	81.5	100	633.86	42.3	11.6
5	11:45	526.4	86.1	78.7	436.53	1.72	41.95	5.61	77.9	255	80	247.4	866.14	115.7	9.6	94.5	112	633.86	42.3	10.2
6	12:45	462.2	85.3	78.8	380.52	1.71	41.7	5.57	69.1	255	80	247.4	866.14	101.2	9.6	82.3	98	633.86	42.3	11.7
7	1:45	470.0	84.5	81.3	381.55	1.71	41.7	5.57	68.5	255	80	247.4	866.14	101.5	9.6	81.7	100	633.86	42.3	11.7
8	2:45	432.4	84.5	81.6	350.83	1.71	41.7	5.57	62.9	260	82	253.0	915.57	95.5	10.1	77.5	92	584.43	38.9	13.0
9	3:45	441.8	84.7	77.5	362.04	1.71	41.7	5.57	64.9	260	82	252.5	916.72	93.3	10.1	76.4	94	583.28	38.8	13.2
10	4:45	441.8	84.7	76.2	362.04	1.70	41.46	5.54	65.4	260	82	252.5	916.72	93.3	10.0	76.3	94	583.28	38.8	13.1
11	5:45	535.8	85.1	75.0	443.21	1.70	41.46	5.54	80.0	260	82	252.5	916.72	97.1	10.0	97.1	114	583.28	38.8	10.3

New System, March 3, 1908

1	7:20	282.0	86.3	72.3	237.80	2.09	50.98	6.81	34.9	220	80	213.5	996.32	59.7	13.5	48.5	60	493.18	33.1	27.8
2	8:20	282.0	86.3	72.3	237.80	2.09	50.98	6.81	34.9	226	80	218.3	985.23	60.5	13.3	49.2	60	504.27	33.8	27.1
3	9:20	291.4	85.7	73.5	243.52	2.10	51.22	6.84	35.6	220	80	214.0	995.16	61.3	13.5	49.5	62	494.34	33.2	27.4
4	10:20	282.0	86.3	73.8	237.08	2.08	50.73	6.78	34.9	220	80	214.0	995.16	59.7	13.4	47.6	60	494.34	33.2	28.2
5	11:20	291.4	85.7	74.2	243.10	2.08	50.73	6.78	35.8	220	80	214.0	995.16	61.1	13.4	48.8	62	494.34	33.2	27.6
6	12:20	338.4	86.1	75.0	283.21	2.09	50.98	6.81	41.6	220	80	214.0	995.16	71.3	13.4	57.1	72	494.34	33.2	23.6
7	1:20	310.2	86.5	76.1	260.27	2.09	50.98	6.81	38.2	225	80	217.5	987.07	65.8	13.3	53.2	66	502.43	33.07	25.0
8	2:20	310.2	86.5	78.3	259.21	2.08	50.73	6.78	38.2	225	80	217.5	987.07	65.5	13.2	51.7	66	502.43	33.07	25.9
9	3:20	291.4	85.6	77.1	241.98	2.09	50.98	6.81	35.5	225	80	217.5	987.07	61.2	13.3	49.3	62	502.43	33.07	27.1
10	4:20	282.0	86.3	76.3	234.12	2.10	51.22	6.84	34.2	220	80	214.0	995.16	58.8	13.5	47.3	60	494.34	33.2	28.6
11	5:20	310.2	86.5	72.8	261.88	2.09	50.98	6.81	38.4	220	80	214.0	995.16	65.7	13.4	52.2	66	494.34	33.2	26.2

DISCUSSION

LIQUID TACHOMETERS

By Amasa Trowbridge, Published in The Journal for Mid-October

Mr. Sanford A. Moss. I have had some experience with liquid tachometers and quite agree with all that has been said about the excellence of this form of instrument for measuring speed. Personally, I believe that a liquid tachometer calibrated by some such means as that described in the paper is the only satisfactory form of speed-measuring instrument which we have.

2 I have frequently seen the attempt made to verify a liquid tachometer by measuring the revolutions with an ordinary revolution-counter and stop-watch, and comparing with the tachometer reading. I have found it a common impression that such calibration is necessary in order to be sure the instrument is in proper working order. It seems to me, however, that the only verification needed is to make sure that the instrument reads zero when stationary. Particular attention should be given to this point and a liquid tachometer should be so made as to be very readily set at zero. Some makes are inconvenient in this particular. If the instrument reads zero when stationary, and if the scale is originally correct, it seems to me certain that all other readings will be correct without verification by revolution-counter.

3 In the form of instrument described by Mr. Trowbridge, there is a horizontal shaft and a stuffing-box. In practical experience with this form of instrument, I have found it difficult to keep the stuffing-box absolutely tight and probably some of the troubles attributed to evaporation may have been due to a leaking stuffing-box. If the instrument can be conveniently stopped frequently to adjust the zero, a slight leakage will give no difficulty. To do this is often very inconvenient, however, and the instrument must be used without stopping for perhaps a day at a time. In such cases the necessity for resetting the zero is a very serious matter. A form of instrument with a vertical shaft has been proposed, in which this difficulty is obviated. I hope a precise instrument of this form will be made commercially.

THE ENGINEER AND THE PEOPLE

By Morris L. Cooke, Published in The Journal for Mid-October

ABSTRACT OF THE PAPER

Many present-day conditions, among them the broadening of human knowledge, and the generally recognized necessity for coöperation, will force the engineering profession and the individual engineer to take a more direct interest in affairs affecting the public. This will be especially true in matters involving engineering. A corresponding change is already in progress in other professions, notably in the medical profession. If engineering is to take full possession of the field which the public is willing it should occupy, more effort must be put forth along lines of purely public interest, and every opportunity be given the public to coöperate with the engineer. To execute this general policy the appointment is recommended of a standing committee to be known as The Committee on Relations with the Public.

DISCUSSION

Dr. Alex. C. Humphreys. I find myself very fully in accord with Mr. Cooke's proposition and arguments, and I might almost be willing to let my discussion consist simply of this expression of agreement; but by direct reference to certain parts of the paper, I may add emphasis to Mr. Cooke's main proposition—that this Society should in a definite way recognize and meet its responsibilities to the public.

2 As individuals our responsibility increases as our capacity for service increases: with increased power comes increased responsibility. As engineers, we must bear a definite responsibility by reason of our special training, not only as members of a profession but as citizens qualified along certain specific lines. And as individuals, this responsibility will vary in direction and measure according to our capacity to advise along certain well-defined lines.

3 Many of the questions most prominently before the public today, and receiving constant attention from our legislators, munici-

pal, state and national, are involved in the problems of industrial management, in connection with which the guidance of the qualified engineer, under proper selection, can be made available for the benefit of the people at large.

4 It is manifest that much of our law-making during the past few years has been conceived in ignorance and born of misinformation. Much of this misinformation has been furnished by doctrinaires; not a little of it by technically educated men who failed to recognize that competency in one line of engineering or industrial activity does not necessarily imply competency in all other lines. So the responsibility rests upon the engineer, not only to use his knowledge where it can be employed authoritatively for the public good, but modestly to withhold his advice unless his technical training has been adequately supplemented by practical experience.

5 Here come in the advantages accruing if this responsibility to the public is recognized by such an organization as ours, rather than if its recognition is confined to individuals. Advice offered by our Society, or by any other engineering society of established reputation, would be that which had stood the test of discussion and criticism by the membership at large or had been carefully canvassed by a competent committee, as suggested by Mr. Cooke.

6 The American Gas Institute, organized some three years ago through the amalgamation of a number of the more prominent associations of gas engineers, has two standing committees—with power to appoint sub-committees—which have general charge of all investigations and the procuring of papers for its conventions; these are the Technical Committee and the Public Relations Committee. That the problems of public relations are more definitely pressed upon the attention of the members of the Institute than upon the members of the A. S. M. E. is at once apparent, but a little thought will go far to convince the indifferent that a considerable number of our members are interested in vocations dependent upon a correct understanding by the public and its representatives of certain general principles of industrial management.

7 Mr. Cooke says (Par. 22), "It is no longer possible for either a profession or a craft to corner information and hold it for its own use." I contend that, if such an attempt is made, the layman, or public, will in all probability accept the false instead of the true, to the disadvantage of those interested in the profession or craft. This suggests as a motive, "Honesty is the best policy," but a right course taken from a selfish motive is better than a wrong course, and we may look hopefully for the development of higher motives later.

8 The engineers of this country individually, and still more so, collectively, are responsible as units of a self-governing people, to guide public opinion aright, wherever they are specifically qualified, and so to guide legislative and executive action. Perhaps we may be more inclined to recognize our responsibility, if we constantly bear in mind that, *as engineers*, we are not scientists, but that we are charged with the duty of practically applying the truths of science to the solution of the world's industrial problems.

9 This responsibility should be kept constantly before the students of our schools of engineering. Especially should this be a feature of the instruction in the departments of engineering practice; though opportunities for impressing upon students their duty as citizens are not confined to any one department.

Dr. Talcott Williams.[1] The suggestion in this paper on The Engineer and the People is the natural and fortunate product of the joint experience of the mechanical engineer and the journalist, of the lessons of the technical school and of the newspaper office. Mr. Cooke has had both; few have. Guided by this twin experience of the engineer and the newspaper man, he has pointed out why the calling which has a more severe technical training than any other and gives this age, in the various work and achievement of engineering, its crowning difference from other ages, has less weight in public affairs and on public opinion than any other. Engineering creates modern life. Take away engineering, and we are what our predecessors were. Add engineering, and the modern world is.

2 Yet this creation pays less attention to the word of its creator than to any other factor in its daily being. What engineer here has not seen in some public work or design money wasted today, or waste made sure in the near future, for lack of engineering advice known to engineers? The contractor overrides the engineer. The builder gets the better of the designer. The politician controls the technician. The railroad from beginning to end is engineering. Can any man here feel that the engineer, as such, in all his various functions, has his fair share and say in the railroad? A reader of technical journals from my youth up, when I became a reporter, nothing amazed me more, after I had read with the keen interest of one who knew only enough to admire, of the brilliant skill with which some engineer had made the impossible, possible, than to go to report the "opening" and find everybody on hand, and sometimes, everybody's name on the work,

[1] Talcott Williams, LL.D., of Philadelphia.

save the one man who had made it famous, but had not made himself known. Somewhere at the back of the platform, if he was lucky enough to get there, strolling uneasily around unnoticed, was the man who had a right to say, "I am it." As Proverbs has it, when the poor wise man had "saved the city," no man "regarded his name." I may exaggerate, but I am sure there are men here who have felt the proud humility of skill which finds in the consciousness of work done a reward greater than any other.

3 The army engineer officer, it is true, rarely has to suffer this. He has his full share of the limelight. But there are several hundred civilian engineers working on government jobs, some of them men of great ability, as we who read behind and see through the official reports know, who have not the position, the recognition or the pay for which their work calls. Would it be possible for these men, some of them grown gray in government service, to stand where they do, if the calling of engineering had the public ear and the attention Mr. Cooke urges and proposes to secure? Is it not true that the engineer, oftener than any other highly-educated man, sees

> Art made tongue-tied by Authority,
> And Folly, doctor-like, controlling Skill.

4 The reason is simple. In every social system, a man or men, a class or a calling, will have weight, influence and authority in proportion to its access to the center and origin of authority and power. Let this center be the King, as in France for centuries, and the courtier will rule, every noble will seek Versailles, and it will be true, as Nicholas I of Russia said, when Victoria asked him who his greatest noble was, "The one I spoke to last." Let a class rule and men will sacrifice self-respect and become snobs to enter that class or to know its members, as has been true in England under an aristocracy. In a broad democracy, the men who have access to the mass are certain to have weight. Look at the weight of the lawyer, always reaching the public. When in New England men went to church, the minister counted. The "political machine" itself is but a way of organizing the mass vote.

5 The engineer in all this has the disadvantage of a silent profession. His calling is recent. Its work is not understood. Much is incomprehensible to the average man. How few men, not engineers, can even read with comprehension recent reports on the failures of two great bridges at Quebec and New York? The working of a proposed statute can be made clear to any man; the death-rate from disease any community can understand: while to read a strain sheet

calls for years of training. It is true of most engineering problems and their solution, that even the educated man, much less the mass of men, can understand only results. The engineer who secures these results, as I have already pointed out, too often fails to get credit. Failing to get credit, he fails to have weight with the community, which blunders and wanders for lack of his guidance.

6 The time of a good engineer is too valuable to civilization to be used up in mere personal agitation. There is besides something in the engineer's training which makes him an intellectual aristocrat; what he knows, he knows. He loathes personally putting himself forward. He it not made that way. Words are not his tools.

7 The practical result is that there is no class so able and so silent, none so visible in its work and so invisible in its personalities. There is today no body of men, knowing so much, which influences public opinion so little, none whose work educates the public, which rules us all, so little. Who of you does not know of engineering blunders and engineering wastes because the large public of voters and the small public of directors are ignorant of what has been done in engineering? Both are ignorant because your profession does less than any other to educate the public. Look at the work for public health done by doctors, for new laws by lawyers, by my own calling in awakening the public. The engineer will never stand where he should in the modern State, until he too discharges his duty at this point. The doctor has his societies, the lawyer, his associations. Are your societies doing their share? Neither doctor nor lawyer speaks individually, nor need the engineer; let local and national engineering societies speak.

8 Take the stationary engine. We all know that in this country it is insufficiently protected against injuring and maiming and killing those at work about it. You know the safeguards that should be imposed by law to keep the balls on a governor from slaying, for instance, or to make the work of the oiler safer. Some day you will face a fool law on these and other points of danger, hampering all your work as mechanical engineers. Why ought not your societies so guide and frame the laws we are sure to have, to make our engines and machines safer? A large concrete construction collapsed in Philadelphia not long ago, slaying helpless men, because a contractor found it easier to steal professional plans than to hire professional skill. Suppose on the heels of that disaster a Philadelphia Society of Engineers had spoken through the newspapers clearly, emphatically and authoritatively? Was this not as much their duty as for a medical society to deal with deaths from pestilence?

9 Each year our State legislatures have before them dubious legislation on engineering issues. Some is sentimental ignorance. Some is ignorant sentiment. Some is sheer "strike." Some is wise. Medical societies take up medical laws. Legal committees and associations educate the public on their subjects. Why should not state and city engineering societies have their committees on legislation? The newspapers will always gladly print this collective, authoritative opinion. They worry you now, individually, for half-baked verbal utterances, hastily given and inaccurately reported.

10 After the Iroquois theatre disaster, every American city tried to set its theatrical house in order. At that moment, the careful technical utterance of anybody speaking for your profession would have been heeded all over the country. If accidents in machines causing loss of life were reported upon by mechanical engineers in our cities, the public would soon "stop, look and listen" for this utterance of the mechanical engineering conscience of the community, as such collective opinion would soon come to be.

11 If this were done systematically, if failures in construction or in design in public work had lucid authoritative exposition from engineering societies, if legislation were followed, if expert remedies were proposed by engineers for known evils, the public would come to look to these engineering societies for advice and the entire status and position of the engineer would change, and he would have the weight he should have as the maker of our current civilization, because he would be doing his duty in educating the great public, our sovereign, yours and mine, our larger self.

Hon. George W. Guthrie.[1] There are many serious public evils of which the people are keenly conscious and which they would like to have remedied, but because for want of technical knowledge they cannot see a remedy, they hesitate about undertaking any agitation for relief.

2 Merely to point out these evils does not materially help the situation; if, however, men whose training peculiarly fits them to deal with these questions and whose character and abilities are such as to command the confidence of the people, would point out both the evil and the remedy so that the people could understand what was needed, how to do it, and what it may cost, I believe progress would be more sure and rapid.

[1] Hon. George W. Guthrie, Mayor of Pittsburgh.

3 I know it is much to ask, but the reward would be the consciousness of a great public service and the relief of the people from remediable evils from which they suffer unnecessarily.

Mr. Fred. W. Taylor. Mr. Cooke's paper is so new and advanced that at a first reading it is difficult to grasp the everyday practical importance of his ideas. And the question which most of us will ask is, just what are we to do as a society toward coöperating with the public that we are not now doing as individual engineers? For after all we are now engaged in our daily work in coöperating either with individual members of the public or with the official representatives of the public.

2 It would seem on second thought that there must be a large range of subjects in which the Society either through committees or through a debating section, or through its employees (the Secretary and his executive staff) can coöperate with the public in a manner which would be entirely impossible for us as individual engineers.

3 Mechanical engineering problems are constantly recurring in the management and development of our cities, for example, which if not identical are yet similar. And it is to our Society, through its appropriate committees, that public officials should properly look for the standards, both mechanical and in method of procedure, which they should use in the solution of these problems.

4 The standards recommended by the committees of our Society should have (and in fact have had) a weight and influence far beyond that of any individual engineer, however eminent. One of several illustrations of this will be found in the standard method of making boiler tests recommended by our committee, which has been for several years the standard practically accepted throughout this country, and is likely to remain so.

5 It should take but a few years of active help and coöperation with the public for us to become the accepted authority to which both the legislative and administrative branches of our municipal, state, and national governments would turn both for general advice in framing legislation, drawing specifications, etc., and in the selection of engineers to carry out our public works.

6 As we all know, our most able and public-spirited Secretary has gained the complete confidence of the Administration at Washington by the efficient manner in which he helped the President in making a success of the White House Conference on the Conservation of our National Resources.

7 But few of our members, however, have heard of another instance in which our Society has been of great help to the Administration. Mr. Rice, this summer, and on very short notice, at the request of Dr. Rowe, chairman of the Delegation of the U. S. to the Pan-American Scientific Congress, secured 16 papers, some of them written by the most prominent engineers in their specialties, in this country, which are to be read at the First Pan-American Scientific Congress in Santiago, Chile. These papers should be of the greatest interest to our neighbors in South America, and should materially help in promoting friendly relations with them, and incidentally should direct their attention toward American engineers, and our standards and methods.

8 Das Verein Deutscher Ingenieure, certainly the largest engineering society in the world, and in many respects the most successful, has established perhaps more intimate and useful relations with the people and the government than any other engineering association.

9 Their committee on education, for example, has proved itself of so great practical value to the German government and to the engineering and technical schools, that no important step in this educational field is taken without obtaining their advice.

10 Our society has as yet appointed no committee on engineering education, although we have recently named two members on the Joint Committee for the Promotion of Engineering Education, appointed by the four large engineering societies and the American Society for the Promotion of Engineering Education.

11 Mr. Cooke's paper presents a large and almost unoccupied field of usefulness for our Society, and I trust that we may not be slow in acting upon his suggestions.

Dr. Arthur T. Hadley.[1] I have read this paper with great interest. I believe that the engineering profession will not reach the highest position of influence which lies open to it until it has appreciated more fully than it now does the lines of opportunity indicated therein.

Mr. Frank Miles Day.[2] This paper is significant of a broadening conception of the duties of the professional man, which is in itself but a part of the broadening conception of the duty of every man. At last, though still dimly, we are beginning to see that the welfare of all is

[1] Arthur T. Hadley, LL.D., President of Yale University.

[2] Mr. Frank Miles Day, Architect, Philadelphia, Pa., lecturer on architecture at Harvard University.

of deeper concern than the welfare of the individual, and as a part of this vision, it follows that the professional society at last apprehends that it owes a duty to the public quite as much as to its members.

2 I can hope to throw only a side light on the subject which Mr. Cooke has so suggestively illuminated, and that light, if I am able to throw it out at all, must come from my own profession—architecture.

3 The architect's work being so much in the eye of the public, the fact that the individual practitioner has a distinct duty to the public has long been recognized, and of late years the duty of organizations of architects throughout the world to the public has been increasingly recognized; indeed the discussions of the great parliament of architects, the International Congress, are more largely devoted to questions of public utility than of the welfare of the profession.

4 Judging from the experiences of a sister society, the American Institute of Architects, there is a field of great utility awaiting the efforts of The American Society of Mechanical Engineers. The Institute, though it has occupied the field by no means as fully as might have been desired, has found many opportunities for service to the public. The movement for civic improvement which has made such strides in America has been notably fostered by the Institute and its members. In many of the larger cities, the local chapter of the Institute has taken the initiative in such matters and many civic improvements growing out of such initiative are now being seriously studied or are in course of execution.

5 Among these is the Commission for the Improvement of Boston, established at the instance of the Boston Society of Architects, and now doing serious work upon a most extensive scheme. This Commission has before it projects which for two years or more have received most careful study by the Society and which are presented in the form of admirable drawings and descriptions.

6 In Cleveland, Ohio, the local chapter of the Institute gave the impetus that resulted in the appointment of an expert commission whose splendid plan for the grouping of public and semi-public buildings is now being carried into execution.

7 At the Capitol of the nation, the Institute itself was instrumental in securing the appointment of an expert commission whose members served without remuneration, and formulated plans so convincing by the authority of their excellence, that Washington already seems a different city by virtue of work carried out in accordance with them.

8 Although in these and many other instances, the Institute has done notable work in assisting municipalities to solve difficult problems

worthily, there is still a strong feeling among many of its members that the Institute is not closely enough in touch with the general public.

9 To improve this relation, the last convention directed that a Committee on Relations with the Public be appointed. Although there has not as yet been time for extended work on the part of this committee, its program includes:

a An attempt to secure through the lay press, more worthy criticism of important buildings as they are from time to time completed, more adequate reports of the annual convention of the Institute, and more intelligent notices of architectural exhibitions.

b A series of magazine articles on the status and duties of the architect, on good and bad professional practice, on the evils of ill-regulated competitions and on kindred subjects.

c An effort not only to interpret the aims and ideals of the profession to the public, but to assist the public n the conception that architecture is one of the fine arts.

10 It is hoped that something may also be done to impress upon the public the need of sound training for the architect, something that may help to deter the half-prepared or wholly unprepared youth from attempting a career that requires the fullest preparation, a preparation not merely of a highly special and technical character but a foundation of broad general culture equivalent to that indicated by the degree of Bachelor of Arts.

11 The Institute, from time to time, shows its interest in matters of import to the public by holding open meetings at which such subjects are discussed, or at which it evidences its interest in the sister arts of painting and sculpture by giving exhibitions of them. For example, at the approaching convention of the Institute, the matter of chief public interest will be a splendid collection of the works of Augustus St. Gaudens to be exhibited at the Corcoran Gallery under the auspices of the Institute, at which time the Secretary of State and the French, English and other ambassadors will deliver eulogies of St. Gaudens and his work.

12 Upon one matter which Mr. Cooke has approached I would say a few words. The relation of technical, artistic and learned societies to each other is an important one. At present, these relations are by no means as close or profitable as they might be. To speak only of mechanical engineers and architects: it is fair to say that owing to the

necessity for the services of engineers of high attainment in designing the mechanical and electrical equipment of modern buildings, architects and engineers have been brought into much closer touch than formerly, and to their mutual advantage. But this is an individual affair. Cannot the architects as a body, through their Institute, be of service to the engineers as a body through their Society and conversely cannot the Society be of use to the Institute?

13 With this significant question, I leave the discussion, again thanking Mr. Cooke for his most illuminating paper.

Mr. H. F. J. Porter. Every member of this Society presumably belongs to one or the other of the two classes, *the employed* and *the employer*, which compose "the people" to which Mr. Cooke refers, and if he is as progressive as all of our members are supposed to be he should desire to see the conditions which affect each of these classes, as well as their relations to each other, improved.

2 That need for such improvements exists is evident, on the one hand from the contents of papers presented to this Society and to the "Societies for the Promotion of," respectively, "Technical" and "Industrial" Education, on the subjects of shop organization and management, and on the other hand from the recent establishment of courses of instruction in those same subjects in the representative technical schools and colleges throughout the country. That these improvements are expected to be brought about largely through the instrumentality of the members of this Society is indicated by the fact that many of the latter are in great demand as specialists in reorganizing shops and in improving their systems of management and are being appointed on the staffs of lecturers in these schools and colleges.

3 To no man is presented a greater opportunity to wield a permanent influence over his fellow men than to the employer; for he directs the thoughts and actions of his employees through the major portion of their waking hours, and according to his use of that opportunity he may become a power to uplift or to degrade them and his obligation to his country as a citizen is thereby involved.

4 I have known an employer for whom, as he expressed it, "the best was none too good," whose plant was in every respect a model one and who was still soliciting from his employees and from outside specialists suggestions for its further betterment. His work rooms were not only well lighted and ventilated, but the air was filtered and maintained at a constant temperature by regulating apparatus, summer and winter, and the other sanitary appliances were equally modern. A wash room on each floor was supplied with hot and cold

water, soap, towels and clothes lockers. A simple and wholesome lunch was furnished at cost amid attractive surroundings. Technical and popular literature was supplied with the privilege of taking it home. A beneficial organization fostered by the company supplied a doctor whose duty was to prevent sickness and keep every one in efficient working condition. Long-service pensions tended towards permanency of occupation. Many of the employees held stock in the enterprise which was paying handsome dividends. The employees were receiving the highest wages paid in the industry. They were of the highest grade and were giving their best and willing service.

5 Another employer, the conditions of whose shop as regards comfort, health and working facilities, were so wretched, and the treatment of whose cheap (?) help was so bad that no self-respecting man would submit to them, repeatedly refused to supply any washing accommodations in his plant, until the Molders Union obtained the passage of a law by the State Legislature requiring Foundries to supply wash rooms and the State Commissioner of Labor forced him to act. He then complied with the letter of the law by installing some sinks in a dark cellar of an adjoining building, so inconvenient of access by the molders that they would never go there, and then gloated over his shrewdness in circumventing their plans. He was losing money every month and finally conceived the idea that all he needed to make the place pay was to install a cost system. He stated that there would be no difficulty in introducing any system or methods in his organization as "he had his men thoroughly cowed."

6 It does not require a very vivid imagination to appreciate the difference in the effects produced by the methods of these two men on their organizations and on the communities in which their shops were respectively located.

7 These are two extreme types of employer and there are many intermediate ones, but there is a large class of employers not generally recognized by that name, and yet who are a potent element in affecting the relations between capital and labor in which "the people" are so vitally interested. This is the rich man, oftentimes a banker, who has acquired the controlling interest in a successful enterprise by advancing money to it on account of some friend who has become involved in it. He is an employer by accident. He takes no further interest in the affairs of the enterprise than to get a return on his investment. He puts in charge as manager his friend, who possibly through his ignorance of the principles of management was the original cause of its lack of success. His constant injunction

is to "keep down expenses." The manager gets financial assistance in driblets, for the absentee employer is enjoying himself abroad or on his yacht or is engrossed with his other pleasures and does not wish to be bothered. The low wages, the lapsed pay-days, the frequent lay-offs due to lack of supplies, the unpaid bills for material purchased, are not only the far-reaching causes of inconvenience but sometimes of absolute misery. Such employers consider too lightly the social and economic effect of their methods on "the people."

8 There is little wonder that the labor unions have gained adherents to their ranks, and have found plenty of incentive to use extreme methods in fighting to secure better conditions for their members. If there were no such employers there would be no reason for unions of the type that now exist. Many employers have yet to learn how dependent they are for the success of their ventures, upon their treatment of their employees, which involves their families and the community about them.

9 Your members who are engaged in the work of reörganizing shops will witness that a large proportion of failures in industrial enterprises are due to arbitrary methods of management. Owing to internal improvements in industrial establishments brought about by competition and the general advance of the times, changes in the methods of management of the past have become necessary. These changes are directed away from the centralized or one-man source of authority towards distributed power or committee management. The executives of our largest industrial enterprises are urging their employees to become stockholders, and thus part owners, having a voice in their policy of management.

10 This is a repetition in the field of industrial government of what has taken place in national and religious government, viz: a change from the monarchic or autocratic rule, which was synonymous with tyranny and oppression, to more liberal methods as exemplified in the democratic form of government. This change is not occurring without a struggle. There are still plenty of members of the old school who believe in a ruling class and a subject class, and that the latter have no rights not allowed them by the former. But the overwhelming force of the tide of democracy which we have recently seen sweep away the old order of things successively in Japan, Russia, Turkey, Persia, and China, is making its inevitable inroads in industry to the financial and social betterment of everybody involved. Even children are being taught self-government in their "School Cities," the George Junior Republic and the juvenile courts, and the "honor system" has come to stay in the colleges.

11 Realizing the far-reaching effect upon the industrial future of the country of the failure of the employer to realize the obligations which his privileges entail, efforts have been recently made, by those engaged in the work of shop reörganization, to establish a platform from which they could present their experiences that others might profit from them. Until the present time these efforts have seemed to be premature.

12 Now that our Society is enlarging its scope and offering opportunities for the establishment of sections, to the membership of which others than those qualified as engineers are eligible, it seems to me that the opportunity is here presented for managers and those interested in management to get together for the interchange of views and the discussion of those questions which have so important a bearing on the industries of this country, and therefore upon "the people" at large who are directly affected by them.

Mr. Arthur L. Church.[1] In my invitation to discuss this paper reference was made to the methods by which the University of Pennsylvania keeps itself before the public in order that the public may take an intelligent interest in it. Special reference was made to the publicity given the dedicatory exercises of its new engineering building.

2 The primary object of those in charge of the ceremonies was to dedicate the building in a manner befitting the dignity of the University and the importance of the event. Preparations were begun nearly six months in advance. The Provost of the University appointed a committee, with the head of the bureau of publicity of the University as its secretary. This committee, having the power to add to its own number, selected members from the trustees and engineering graduates from 1874 to 1901. These were divided into sub-committees on invitations, exercises, reception, publicity, finance, and dinner. Communications were established between this general committee and representatives from each graduated class of the University. The cost of the day's exercises and entertainment was about $5000, which was raised by the finance committee, chiefly among graduates of the engineering courses and engineering establishments in the vicinity of Philadelphia. The publicity given the event in the daily papers was chiefly due to the secretary of the general committee, Mr. George E. Nitzsche, and that given by the technical press to Dr. Henry W. Spangler and Dr. Edgar Marburg.

[1] Mr. Arthur L. Church, of Philadelphia.

3 About 23,000 invitations were issued, and representatives were present from institutions of learning, technical societies, and foreign, national, state and city governments. Degrees were conferred upon distinguished engineers; an address was delivered by Provost Harrison and by Dr. Alexander C. Humphreys for civil engineering, and Dr. Frederick W. Taylor for mechanical engineering; 2000 guests were entertained at a luncheon and 250 at a dinner, at which speeches were made by well-known professional men.

4 I heartily agree with Mr. Cooke's suggestion that technical societies should take an active and altruistic interest in questions affecting the public weal. This has been done in many instances by the Franklin Institute of Philadelphia and I believe it accounts in some measure for the hold which that institution has on the public and the interest which the public takes in its welfare.

Prof. A. W. Moseley. It must be admitted that the greater part of the work done by the mechanical engineer is of a kind that is unseen, unknown and unappreciated by the general public. Civil, architectural, naval, and certain other great divisions of engineering are more fortunate than we in this respect. It is true that an occasional pumping or power station, or locomotive, or "Machinery Hall" attracts general attention, but so many of our structural activities are confined to dark basements, narrow passages, and crowded shops and factories that they are known only to those who are brought into contact with them by their daily occupations.

2 It is fortunate that industrial engineering, so-called, is largely a problem of the mechanical engineer and is receiving well deserved attention from him. An intelligent and unselfish meeting of his opportunities in this field will bring him before the public in a more evidently useful and generally prominent light than ever before. For instance (and this is one of the problems of the industrial engineer), it is impossible to over-estimate the good that would be brought about were this Society, as a Society, to take a stand for the universal introduction of safety appliances and were every member to urge such adoption in all instances met in his practice.

3 But there is the æsthetic side as well as the ethical. Do we mechanical engineers give enough weight to the element of beauty in our designs of machines and in our layouts? The following quotation is from Dr. Waddell's De Pontibus: "In all structural work the subject of æsthetics must be duly considered: and all designs are to be made in harmony with the principles thereof, to as great an extent as

the money available for the work will permit or the environment of the structure calls for." This quotation is given because it is so well expressed and not because it is believed to be necessary to turn to another branch of engineering for such a statement. "Money available" and "environment," these are the sticking points. But more money is being made available, and with it, better environment; and the opportunities of the mechanical engineer to devote serious attention to æsthetic features are increasing daily. Here, too, he will meet the public and the public will thank him.

Mr. James M. Dodge. I am convinced that the suggestions of the author have touched sympathetic chords in the minds of all of us. I believe every one realizes how much in connection with the subject has not occurred to him before in crystallized form. I personally feel as I have felt when after reading an able editorial I am prompted to say, "That is exactly what I thought," but if any one had asked me to tell exactly what I thought before I had read the editorial I would not have covered myself with glory. It is not necessary now to consider ways and means for putting Mr. Cooke's suggestions into force because I believe now that he has set the ball rolling, it will never stop, but rather be accelerated in its progress by the professions for all time to come.

Mr. Ambrose Swasey. The field of the engineer is already very broad, much broader than when I joined this Society as one of its charter members. But there are still broader fields ahead of us, and I think this paper contemplates our entering these larger fields of usefulness.

2 A few days ago I had a talk with Congressman Burton. As you know, he has for several years been Chairman of the Rivers and Harbors Committee, and is one of the able men in Congress. In speaking of the work of the engineer in connection with this conservation movement, he said, "By all means the engineer should be found in the front rank, for he is a most important factor in this splendid work which we are about to undertake, a work of which we have just reached the edge, and which will go on and on, increasing as the years progress."

3 What Mr. Cooke has said means a step in advance for this Society and for the engineers of this country. It means that we are going to pay more attention to public matters, not simply to our private interests, but to the good of the people as a whole. In this connection I wish to present the following resolution:

4 Resolved, that we recommend to the Council the appointment of a Professional Committee, to investigate, consider and report on the methods whereby the Society may more directly coöperate with the public on engineering matters, and on the general policy which should control such coöperation.

MR. CHARLES WALLACE HUNT. This resolution, which Mr. Swasey has proposed, is really broadening the work of the Society. It may become a national engineering and economic movement, which may develop later as a section of the Society. With that in view, I second the motion made by Mr. Swasey. [The resolution was also seconded by Mr. Fred. W. Taylor and unanimously adopted.—EDITOR.]

PROF. F. R. HUTTON. It has been suggested, in pursuance of the recommendation of Mr. Cooke (Par. 6), that a Committee on Relations with the Public should be created, following the analogies of the other Standing Committees of the Society.

As this calls for an amendment to the Constitution, which it is not in order to present to this meeting, I will at this time only give notice of the purpose, pursuant to the provisions of the Constitution, to amend Article C45, at the Spring meeting of the Society, at which such amendment can come up for discussion.

MR. OBERLIN SMITH. I agree in general with the views of Mr. Cooke and his idea of a standing committee upon Relations with the Public. It may be that such a committee might also act as a Committee upon a "Code of Ethics" a matter which other societies are taking up and which we certainly cannot afford to neglect.

2 It is true that engineers as a body live too much to themselves and for their work, and do not sufficiently affiliate with the public in general. Perhaps we are too busy and too modest to attend to anything but our own work, or to exploit ourselves before an admiring public. The present condition is partly our own fault, and I would here urge, as I have in an annual address upon previous occasion, the higher self-cultivation of all engineers, in whatever branch of the profession. It is much to be regretted that, with the exception of West Point and Annapolis, few of our colleges and still less our technical schools, pay enough attention to this matter. In furtherance of these ideas, would it not be a wise policy for this Society to urge upon the technical schools of our country the adoption of broader and more liberal schemes of education, especially during a student's earlier years, that he might be caught (and taught) young?

3 From another point of view the public at large are to blame for not more thoroughly cultivating and recognizing engineers as the men who are creating, developing and maintaining the whole fabric of modern civilization. Many of them are doing splendid work in musty offices and drafting rooms for very moderate salaries, while the men who are exploiting and financing this work (with much less education, and in many cases smaller brains) are getting the big salaries and enjoying the credit of developing great industries and inaugurating public works.

4 This public has not yet even learned, in many cases, the difference between the machinist who shapes the iron into a steam engine, or the engineman who oils and cleans it and watches it run, and the professional engineer who, with the necessary ability, education and experience, has designed it. Surely it is to be hoped that our nomenclature will be improved in this respect, that we either will drop the name of engineer or try in earnest to limit it to professional men, using other names for the entirely different lower grades just mentioned.

5 It is also sincerely to be hoped, and I think with a good chance of early realization, that professional engineers, with their carefully trained minds, their years of experience in administrative work and their logical habits of thought, may occupy more of the public places of our land. Knowing what our profession is and does, it seems remarkable that it is not more often represented in the halls of Congress, in the Cabinet and even in the White House.

The Author. The engineering profession may almost be said to accept the conception of its duty toward the public as outlined in this paper, since all the discussion before the Society, in the technical press and elsewhere, has apparently been favorable. Even those who place the highest value on the work of the engineer are willing to admit that he has failed in this public function. There is little therefore to be gained from further discussion. Carlyle has said that "The end of Life is an Action, not a Thought, though it were the noblest." This injunction comes with added weight to a profession that stands for action, not speculation.

2 It is not too much to expect that The American Society of Mechanical Engineers should lead in the work of transforming this thought into action. Already its committees are showing in their various plannings the quickening thrill of a broader vision. It is nevertheless true that the Society acting as a corporate entity can

be effective in this work only as the individual activities of its members make it possible and as it is held up to the work by what may be called the suggestive influence of individual members.

3 May there not be danger that our progress may be retarded by our holding back as a Society and as individual members in order to take part in some great work which is to benefit the public in a large way? Doubtless there are such undertakings ahead of us. But one small piece of engineering work of a purely public character done by an engineer or an association of engineers with the utmost efficiency and done at once will advance the whole program more than would the proposing of a dozen more ambitious schemes which might one by one die in the process of being discussed.

DEVELOPMENT OF THE HIGH SPEED MILLING CUTTER, WITH INSERTED BLADES, FOR HIGH POWERED MILLING MACHINES

By Wilfred Lewis and Wm. H. Taylor, Published in The Journal for Mid-November

ABSTRACT OF PAPER

The main point in the milling cutter here shown and described is the use of inserted helical blades of high speed steel, mounted in a steel holder to give a solid backing for the blades on the driving side, against which they are held by a soft metal filler on the opposite side, thus giving a uniform support for the cutter blade on both sides from end to end.

Another point is the form of groove adopted to give a slight curvature to the blade across its width, and thus favor the realization of a lip angle from the cutting side. Not only are the blades held more securely in position by the method adopted, but they are also more easily removed when damaged, and new blades can be easily inserted.

The cutting power of a milling cutter built up in this way appears to be beyond the capacity of any machine now on the market, and the endurance of the cutters, as far as experiments have been made, is phenomenal.

DISCUSSION

Mr. Fred J. Miller. Most of us are, of course, familiar with the fact that milling cutters were first used generally for producing forms otherwise difficult to produce at reasonable cost. Parts of small arms and similar things were thus produced as the next step in advance of filing them to the required form and dimensions. Cutting the teeth of gear wheels was one of the first if not the very earliest use of the milling cutter.

2 In all such work the form of the cutter and the ability to keep it near its original form until worn out were the chief considerations; as indeed they still are for many kinds of work. This, more than anything else, probably, has led to the almost universal use of the radial front face for the teeth of milling cutters; because only by

having radial front faces could the problems connected with forming cutters and maintaining their forms be sufficiently simplified to be at all practicable. This seems to have led to what may be called the traditional practice of making the front faces radial in all cutters —even in the plain, solid, spiral cutters whose only office is to remove metal from a plane surface and which can as well be made and sharpened if they have front rake as with radial surfaces for the front of the teeth.

3 Radial surfaced teeth can scarcely be said to cut. They push and jam the metal off. When heavy cuts are taken this jamming becomes a serious matter and front rake is almost a necessity. Even a little front rake is very advantageous when the mere removal of metal from a plane surface is the object sought and it seems likely that such rake will become as common for milling cutters used on such work as it now is for lathe and planer tools and for the same reason.

4 Referring now to the tables at the end of the paper, I would suggest that in the heading of the last column in each table the words "per minute" be added. The figures given in these columns really mean the horse power per cubic inch of metal removed per minute. I would suggest also that another column be added to these tables giving either the cubic inches of metal removed per minute per inch width of cut, or, the number of pounds of metal removed per minute per inch width of cut.

5 Comparisons of the efficiency of cutters can be made only upon their performance per unit width of cut. For example, I find that the maximum performance shown in Table 1 is, the removal of 1.82 lb. of cast iron per minute per inch width of cut; the cut in this case being 3 in. less than the length of the cutter. This is at the rate of 7 cu. in. of cast iron per minute per inch width of cut.

6 The maximum performance shown in Table 2 is the removal of 0.74 lb. of 30 point steel per minute per inch width of cut; or, 2.62 cu. in. per minute per inch width of cut. The cut and the cutter are, in this instance, the same width.

7 In Table 3 the maximum performance shown is the removal of 6.56 cu. in. of steel per minute per inch width of cut.

8 These figures enable us to compare the performances on cast iron with those on steel, which the figures given in the table do not; and they show also the performance of the cutter as distinguished from that of the machine which drove it. The width of the surface from which a given cutter can remove a given quantity of metal per

unit width of cut depends upon the machine which drives the cutter and supports the work.

9 The performance of the cutter is shown by the work it can do per unit of time per unit width of cut; the power and efficiency of the machine by the number of those units of width of cut for which it will stand up and do its work satisfactorily.

Mr. Oberlin Smith. I want to ask the authors of this paper what they found to be the best lubricants (or "coalicants") for cast-iron, for mild steel and for brass respectively, also the best angle of rake, that is the angle with the radial line, in lathe-work, etc., respectively for the three metals mentioned.

2 Changing the subject a little, I ask the membership in general if they have had any experience either with boring tools or milling-cutters made by inserting a set of blades into grooves in wooden patterns, and molding them so that they remain in the sand for the casting of a hub or body about them, the same being hollow to go on a boring-bar or having a shank of its own to insert in a milling-machine spindle. I had some experience years ago in making such tools of from three to nine inches in diameter of mushet steel, finished in a grinding-lathe. It is not practicable to use carbon steel, as heating it for hardening is apt to crack the iron hubs. No doubt this scheme has been tried by a good many people, but with what success?

3 Doubtless high-speed steel cutters could be cast in this way, provided the heat of the cast-iron would not anneal them too much. That is a point to ask Mr. Taylor or Mr. Lewis about, or any one who has found out anything about it. Is there any practical way of using high-speed cutters, and casting them into a hub of iron? It is obvious that a large-toothed cutter can be made more cheaply in this way than in any other, but we do not want the slow speeds of mushet steel.

Mr. Fred W. Taylor. The writers of this paper, as well as that of Mr. DeLeeuw, speak of the "lubricant" used upon the tool and Mr. Oberlin Smith has just spoken of the best "lubricant" to use on a tool. In taking a heavy cut with a tool, in fact in doing any metal cutting in which a chip runs continuously across the lip-surface of a tool (except in the case of a light finishing cut) is it possible to get any lubricant between the chip and the tool? In cutting steel the tool receives a pressure from the chip of about 180,000 lb. per square inch at the spot where the chip rubs upon it.

Is it possible to get any lubricant between two surfaces, one of which is forced against the other with a pressure of 180,000 lb. per square inch on an average, and in which one surface is continuously moving past the other at the rate, we will say, of 40, 50, 60 or 70 ft. a minute?

2 I think this is utterly impossible when the nose of a tool is buried in the steel as it is in taking a roughing cut. The word "lubricant" is a survival from the practice of pouring a light trickling stream of water or oil on a finishing tool from a small water can supported above the tool, the function of the water or oil being to produce a polishing or burnishing effect upon the work. Water was not used in this way to cool the tool and was confined to finishing tools. Doubtless under a light finishing or scraping cut at the last instant a small amount of water or oil does find its way between the tool and the work.

3 On heavy roughing cuts, it is impossible to get any lubricants between the chip and the tool surface. It is, however, possible and desirable, in almost all roughing cuts, to have either water or oil thrown upon the chip and the tool for the purpose of cooling them, since, as pointed out by the writer in his paper, On the Art of Cutting Metals, a tool cooled in this way can cut from 15 to 40 per cent faster than a tool running dry. Cold water is the best conductor of heat, better than any of the oils, therefore it is the best of the cheap cooling-mediums to throw onto a tool. The only object of putting soap in the water on heavy cuts, or of putting soda in the water, is to stop rusting on the machine or work when the water splashes over. Cold water is the proper thing to pour on a milling-machine of this type. It cools better than any other cheap material known, and the cooler it is the better. The use of soda in water, or the substitution of oil for water on roughing cuts, is merely to stop rusting.

Mr. A. L. Deleeuw. Mr. Taylor's remarks upon lubricants brings to mind an experience I had just about one year before the famous Taylor-White steel was brought out. High speed for tools was in the air, and I tried to get results which have since been accomplished in an entirely different way, by simply cooling the tool and the chip. Realizing that it was impossible to force a lubricant of any kind between the tool and the chip, and that at the same time forcing the lubricant somewhere else would not cool the cutting point of the tool sufficiently to keep it from burning out, I had a ring constructed and attached to the compressed air supply. The ring was provided with a

number of small holes focusing at a common center and so adjusted on the lathe, as to bring the focus of all these small streams of air some little distance from the tool point. The air expanded, forming a center of refrigeration easily determined by a thermometer or by the finger. By adjusting the ring in such way that the center of refrigeration coincided with the cutting point of the tool, it was possible—and that was a year before the high-speed steels were brought out—to turn cast iron which had been rejected on account of its hardness, at the rate of 168 ft. a minute, and I do not know how much faster, because the lathe would not pull it. It was even possible to run steel at the rate of 250 ft. a minute, and I do not know how much faster it might have been run, if the lathe had allowed it.

2 This brings out strongly the same point Mr. Taylor has made, that the lubricant simply cools the tool. There is no object in cooling the chip, but of course we cool the tool by also keeping the chip cool.

Mr. Oberlin Smith. I want to go the gentleman who has just spoken one better. Some years ago, before high-speed steels came up, I came to the conclusion that all that is wanted is to cool the tool. The coolest thing I could get was liquid air. Procuring a can containing 15 gal., and taking every precaution to keep it in a liquid condition, I rigged up on a lathe an ordinary two-quart can with a $\frac{1}{4}$ in. pipe and spigot, and filled it with liquid air. I covered it with flannels, and tried to get some of it on the tool, but it would not run. The reason of course was that it expanded so fast in the small pipe that as a gas it pushed the liquid back into the can and held it there. The pressure upon the atmosphere was so violent that it held against a head of several inches. I then put in a $\frac{3}{8}$-in. pipe, but it would not run. With a $\frac{1}{2}$-in. pipe it did run but of course my supply did not last very long.

2 I have not any accurate records of just what speeds were obtained, but I did get a great deal higher speed than with usual ordinary carbon steel. With a one-inch drill the speed could be doubled in cast-iron. The liquid did not get well down among the chips, but if it had been forced down even greater results might have been obtained. If liquid air were properly handled and forced against the tools it would probably be the best cooling-agent we could secure. This, however, would seem wholly impracticable on the score of expense. If it could be forced immediately to the machines it might be effective, but in the ordinary machine-shop we start and stop the tools frequently, and where the pipes would have to be kept

well insulated to keep the liquid from getting warm it doubtless would not be feasible.

3 I had thought of patenting the combination of liquid air with a lathe milling-machine, etc., but Mr. Taylor's high-speed steel came out and cooled my enthusiasm below the temperature of the air. I now hereby give the invention freely to the world—if I am the original inventor of it—because I do not know whether it is really good for anything, and it is too much trouble to find out.

4 It is an open question whether steel gets brittle at low temperatures and would become so if cooled by liquid air. The metal being cut, and the tool itself, would probably become heated enough, however, so that there would not be this effect.

Mr. A. B. Carhart. The subject of lubricants may be a little apart from the main purpose of the paper, but the subject should not be allowed to drop where it is, after the remarks of Mr. Taylor. Why have great advantages been claimed for many years for lard oil and its compounds for lubrication in milling machine operations? The advantages of kerosene mixtures are recognized for cutting aluminum bronze castings and such metals. The greater conductivity of the lighter oil is easily recognized, but is there no other reasonable explanation of the predilection in favor of kerosene over the other oils; and aside from the rusting tendencies of clear water are there no reasons why mixtures of water with various skim milk compounds offered as substitutes for lard oil have any real value? If there are no advantages in oil other than its non-corrosive qualities, why is it that so much of the cutting oil on the market is so strongly corrosive of the machine tool members?

Prof. R. T. Stewart. In regard to lubrication under high pressures, there are industries in which that is effective. For example, in the cold-drawing of seamless steel tubes, if you attempted to draw steel tubes without lubrication, the effort would be futile. If you want a reduction in cross-section of say 5 to 10 per cent, you may use one lubricant successfully; but if you wish to get a reduction in cross-section of say 25 or 30 per cent, by cold drawing, you have to use another lubricant, one that is better adapted to the purpose. I have effected reductions in cross-sections of 33⅓ per cent, by cold-drawing the tube through a die and over a mandril, when using a proper lubricant.

2 I should not be surprised, though I have had no considerable

experience in using lubricants with tools, if even there they had an effect. I do not know what the surface pressure is in drawing a seamless steel tube, but it must be fully as great as the pressure required to lift the chip in tool-cutting. Seamless tubes have been drawn of high carbon steel, and I should think in that case the pressure would be in the neighborhood of 150,000 lb. per sq. in., at least, and the tubes were drawn quite successfully by the use of proper lubricants. Without the use of lubricants, they could not be drawn.

Mr. Fred W. Taylor. It appears to me that the two cases are not in any way parallel. In the tube-drawing the lubricant can be put on the tube before it starts into the die and a certain amount of it will remain upon it while it passes through it. But how is it possible to make a lubricant run uphill to the nose of a roughing-tool which is ploughing its way into a forging and is completely buried at all times beneath the chip? It would be necessary for the lubricant to force its way uphill between two surfaces under 180,000 lb. pressure. The nose of the tool is buried at all times beneath the chip and the chip travels down on top of the tool continuously at the rate, say of 60 ft. per minute. It would be quite as impossible in the case of tube-drawing to force the oil up through the bottom or rear end of the die between the die and the tube.

Prof. R. T. Stewart. I believe it is the practice in milling to apply the lubricant so that it comes in contact with the cutter before it enters the metal, and some of it will surely cling to the cutter, just as in drawing seamless tubes. I had in mind the case illustrated in the paper, which is upon milling cutters. In milling it is always possible to apply the lubricant to the cutter.

Mr. Fred W. Taylor. In my preceding remarks I had in mind a lathe tool. In the case of a milling-cutter I stand corrected by Professor Stewart—it is possible to get a lubricant onto the lip surface of a milling-cutter before it starts into its cut and in doing fine finishing-work with a milling-cutter a lubricant is frequently desirable. The large milling-cutter under discussion is for taking heavy cuts and in its case the lubricant is of no use. In using this cutter properly an enormous stream of water is thrown on the blades for the purpose of cooling them so as to get a higher cutting-speed.

2 Answering Mr. Smith's question as to the possibility of pouring cast-iron around a high-speed blade, if you treat the blade so as to

give it the best high-speed properties, it must be heated, say, to a high heat between 2000 and 2400 deg. fahr., and then cooled continuously to below 1200 deg. If during the process of cooling from the high heat down to below 1200 deg. it is reheated, even for a short time, the high-speed property will largely disappear, and if during this cooling operation it is reheated for the space of a few minutes, its high-speed is almost entirely lost. Suppose you give a blade its high-speed properties by heating it to a temperature of 2400 deg. and allowing it to cool, and then put this blade back into molten iron which is at a temperature, say, of 1800 deg. This reheating would largely destroy the high-speed properties of the blade. If high-speed steel is heated beyond 1250 deg. and held there for two minutes, the high-speed qualities will be almost entirely gone. And they will begin to return to the blade a second time only after a temperature of 1725 deg. has been passed. Then again, even although its high-speed properties were partially restored to it by heating it, say, to 1800 deg. the grain would be coarsened to a great extent. If high-speed steel is held at a heat above 1800 deg. for even ten minutes it will deteriorate, and if held there for an hour it will become about as brittle as chalk.

3 For cutting brass the tool should have very little if any back-slope or side-slope. A brass-cutting tool should be almost a scraper. Its cutting-edge should not be rounded out in the least, however, or allowed to be in the least dull. Brass tools should for the most part be whitted after being ground. For phosphor-bronze the rate must be different. Tools for cutting steel as hard as fire steel or harder should have 5-deg. back-slope and 9-deg. side-slope. For cutting cast-iron and medium steel they should have 8-deg. back-slope and 14-deg. side-slope; for mild steel, 8-deg. back-slope and 22-deg. side-slope.

Prof. J. Burkitt Webb suggested in regard to the plan proposed for using liquid air as a cooling-agent that it might be as well to conduct the air through the pipes before it was liquefied, and allow it to liquefy in a spray as it came from the nozzle. It would be better than water in some respects as it would not require a drain-pipe to get rid of the waste. He asked if experiments had been made to ascertain how long oil will stick to the surface of cutting tools. He referred to the operation of his viscous dynamometer in which metal discs revolve rapidly in a case filled with water, which is constantly supplied fresh to keep it from heating unduly.

The hands of experimenters had of course been in contact with oily tools, but had been wiped as clean as possible with new cotton waste; yet it was found that oil enough remained on the hands to lubricate instantly the stream of water supplying the case, and reduce the friction 10 per cent. On removing the hand, the friction would creep back to normal in a minute or two.

Mr. Miller. As to the pressures between the cutting tool and chips, why is it when you cut steel dry the surface of the chip is rough and dry, and when you put water on it the surface which has been in contact with the cutting tool is polished?

2 We all know that in chasing threads in the lathe, especially on tool steel, lard oil will enable results in the way of a smooth surface which are not obtainable by lubricating oils or so far as I know with any other substance. If Mr. DeLeeuw noticed whether the surface of the chips which were turned from his steel at the rate of 250 ft. per min. were smooth as when a lubricant is used, or whether they were rough as is ordinarily the case when turned dry, it would throw light upon this matter.

The Authors. In presenting this paper the authors were well aware that they had hardly begun to demonstrate the possibilities of high-speed steel in a milling cutter of the type described, and their chief object in bringing it to the attention of the Society was to reap the benefit of discussion. We are very much pleased, therefore, to adopt the suggestions made by Mr. Miller in regard to the tabulation of results.

2 We want to know, of course, the maximum performance of a milling cutter per inch of face for every size of cutter made. This naturally depends upon the strength of the cutter blade when the cutter is short and on the strength of the arbor when the cutter is long. We do not yet know on what length of cutter the full strength of the driving arbor can safely be thrown, but from experiments we believe that the 3½-in. arbor used to drive our 8-in. cutter 18 in. long would be overloaded before the cutter blades, on an evenly distributed cut.

3 We also know that the cutting speeds were very low, and that with more power and higher cutting speeds our results might easily be multiplied two or three times. The present problem is not what the cutter can do, but how it can be driven at its full capacity. The discovery of high-speed steel has immediately created a general demand for more powerful machine tools, but its adaptation to mill-

ing cutters has progressed more slowly and there are no milling machines on the market today capable of driving our cutter to its full capacity.

4 Though we do not yet know the capacity of our cutter blades per inch of length, we can estimate pretty nearly on the capacity of a driving arbor $3\frac{1}{2}$ or 4 in. in diameter and, allowing 20,000 lb. per square inch as a permissible shearing stress in a 4-in. arbor, we find it capable of driving a cut of about 60,000 lb. on the periphery of an 8-in. cutter. Our cutting speeds on steel varied from 50 to 80 ft. per minute without distressing the cutter blades at all and without any discoloration of the chips, the maximum thickness of which seldom exceeded 0.005 in.

5 In Mr. Taylor's treatise, On the Art of Cutting Metals, 60 ft. is given as the proper cutting speed for a $\frac{3}{16}$-in cut, $\frac{1}{16}$-in. feed; in Paragraph 1186 it appears that the same cut can be taken with a straight cutting-edge 1 in. long at 40 per cent higher speed, or a speed of 84 ft., and in the latter case the thickness of the chip is 0.017 in. It also appears that by the use of water this cutting speed might be increased to 110 ft., all on 33-carbon steel. In our milling cutter, however, we have a shaving not one-third as heavy, and each blade cuts about 5 per cent of the running time and cools off under a stream of water during the remaining 95 per cent. The conditions are therefore particularly favorable for a high cutting-speed and it would not be at all surprising if we could take a cut of 60,000 lb. at a speed of 150 or 180 ft. a minute. This means that 300 h.p. might be consumed in milling and that with an efficiency of 75 per cent in the milling machine 400 h.p. might be required to drive it. Such enormous power concentrated on an 8-in. cutter may yet be realized, but the problem will be to design bearings that will carry 60,000 lb. at a speed of 75 or 80 r.p.m. They cannot be very long to distribute such a load properly and must be kept cool under about 1000 lb. per square inch. A machine with half this driving power would be far beyond common practice today and it is pretty safe to predict that our milling cutter will exceed in capacity any machine that may be built for some time to come, except of course when the cutters are short and the strength of the cutter blades becomes the limiting factor.

6 So much for the future development of the milling machine; but the all-important factor of interest to the user of the present type of milling machine is, how does this cutter compare with the various types of inserted blade cutters now in use. We have carried out a series of comparative tests with various types of inserted

blade cutters and have found that when operated under exactly the same conditions our cutter showed a saving of 50 per cent in consumption of power for a given amount of material removed, and that the life of the cutting edge of the blades was double that of other types of cutters where straight inserted blades were employed.

7 The values of various lubricants and the effects of various lip angles on different materials are questions so thoroughly answered by Mr. F. W. Taylor that we need say nothing further.

EFFICIENCY TESTS OF MILLING MACHINES AND MILLING CUTTERS

By A. L. DeLeeuw, Published in The Journal for November

ABSTRACT OF PAPER

This paper points out the desirability of indicating the power of a machine tool by the amount of metal which it is capable of removing rather than by the size of driving pulley and belt. It describes some tests made for the purpose of ascertaining the metal removed and the capacity of several makes and sizes of milling machines. It also shows the results of tests made for the purpose of finding the net horse power required to remove a given amount of metal under various conditions of feed and speed. It further gives the results of tests determining mechanical efficiency of the feed mechanisms of various milling machines, and shows why it is important that this efficiency should be made higher than is usual. It describes the tests determining the mechanical efficiency of the driving mechanism of one make of machine. It further gives results of tests showing that improvements in cutters, more than improvements in machines, may ultimately reduce very materially the power required for removing metal on a milling machine.

DISCUSSION

Mr. Fred J. Miller. Referring to Par. 4, it is, of course, familiar to the author that although the motor drive has emphasized the fact that machine tools are used for widely varying kinds of work, yet long before the electric motor came into use machine tool builders expected their machines to be called upon to do work varying from the roughest and heaviest to the lightest and most refined. Standard, or commercial, machine tools always have been and probably always will be a compromise based upon that fact.

2 A 16-in. lathe, for instance, can be built capable of taking heavy cuts from steel forgings, say 12 in. to 16 in. diameter; but such a lathe would be nearly useless for a great deal of the work that 16-in. lathes

are called upon to do. Much the same considerations apply to milling machines and this brings up the question as to whether or not a milling machine of the column-and-knee type should be so built as to take very heavy cuts, or be expected to do so.

3 Machines of this type are more convenient of access than any other and are preëminent for the facility with which they can be manipulated. This fact peculiarly fits them for work of a certain kind,—jobbing and tool work, constantly changing in character, for which the machine must be constantly changed in its adjustments and the operator must be able easily and clearly to see what is going on. On such work these features are generally more important than capacity for heavy cuts.

4 Generally speaking, heavy cuts are taken on regular manufacturing work where a number of pieces alike are handled at one time and at a single setting of the machine. On such work facility of access and adjustment, though still important, are unimportant compared with the ability to take a heavy cut when called for.

5 That the knee-type miller is, in its original form, ill-adapted for heavy cuts is shown by the now general adoption of "harness" designed to connect the outer end of the cutter arbor with the outer extremity of the knee and thus reduce the springing and vibration due to reaching out from the supporting column with the cutter arbor and then reaching out with the work-support to meet the cutter. I have seen millers of the column-and-knee type taking surprisingly heavy cuts; but it has never seemed to me that such a machine should be called upon to do it. Where heavy cuts are to be taken machines of other forms seem to be desirable.

6 In Par. 9 of the paper, reference is made to belt power and gear ratio. I have very seldom seen belt speed and gear ratio both specified in a machine tool; it is sometimes done, but I think, not often. Of course if we know the belt width and speed and something of the construction of the machine we can deduce, at least approximately, the turning force that will be applied to the cutter arbor. If we know the belt width only and the gear ratio we can do the same thing.

7 Referring to Par. 19, I think it would be desirable to include with the paper a drawing of the driving gear of the machine designed by the author. I believe such a drawing has been published elsewhere and that the construction is not regarded as a secret. It would help very much toward making complete the record here presented if such a drawing were to be included in the paper.

8 Referring to Par. 28 and 29, it would be interesting to know

something of how the tests there referred to were made. From the nature of the case we would naturally conclude that the force exerted by the cutter against the feed motion of the platen must be about equal to the force exerted by the feed mechanism to move the platen. In fact, in the case of a very deep cut, a considerable proportion of the force exerted in rotating the cutter arbor is not exerted in directly resisting the feed motion, but in lifting the platen of the machine from its seat. It is a familiar fact that, where a stem cutter or a face cutter is applied to the work in such a way that as much of the cut is above the center line of the cutter as below it, practically no force is required for the feed, so long as the cutter is sharp.

9 In general we may say that, other things being equal, the force required to feed the platen of a milling machine will decrease per unit of metal removed per turn, or per minute, as the cut is increased in depth. At a depth of cut equal to the diameter of the cutter, it is probable that very little force is ever required for the feed motion, except to overcome friction, unless the cutter be dull. But for wide cuts of no great depth, the conclusion would seem to be inevitable that the force applied to rotate the cutter and the force applied to move the platen against the cutter are practically equal. If these two opposing forces are substantially equal for shallow cuts, and if, as the cut grows deeper, the force required to rotate the cutter increases in a faster ratio than that required to move the platen, as undoubtedly is the case; and if, as mentioned in the paragraphs referred to, the peripheral speed of the cutter is 40 ft. per min. and of the platen 10 in. per min., we have a speed ratio of 48 to 1 and it is obvious that the power consumed ought to be in the same ratio; or, in other words, the power required for the feed should be slightly over 2 per cent of that applied to the rotation of the cutter, instead of over 66 per cent.

10 It is true enough that results of tests are generally to be preferred to those of deductive reasoning, but it would be interesting to know if the tests that showed that 40 per cent of the power applied to the milling machine to be used to drive the feed-motion, represent actual practice.

Mr. Wilfred Lewis and Mr. Wm. H. Taylor. This paper presents interesting and instructive data in regard to the performance of a milling cutter, and Mr. DeLeeuw is to be congratulated upon the admirable manner in which his work has been done. We have also made some tests upon a milling cutter of different construction, and although we have not gone into the subject in the same way, we are

quite willing to accept the results derived by Mr. DeLeeuw in regard to machine efficiencies as fairly applicable to other machines, upon which we have tried our cutter. We are even willing to admit that the Cincinnati milling machine may be more efficient, and think that 60 per cent would come nearer to the efficiency in our case when the motor is included on account of the additional gearing required for the heavier drive. His method of determining the efficiency of his milling machines by coupling two together and measuring the current absorbed and given off is very ingenious, and gives results in all probability pretty near the truth. We believe, however, that the counter efficiency is never quite equal to the direct efficiency. This is obviously the case where worm gearing is employed, and it must be true to a lesser extent in all cases where speed is reduced through a train of spur gearing and then increased again through a similar train.

2 If Mr. DeLeeuw had carried his experiments further he probably would have determined a higher efficiency for the direct drive of his milling machines. We are willing, however, to accept 75 per cent as a fair average and on this basis it appears that the best results obtained in slab-milling ran from 0.45 to 0.55 cu. in. per min. for one horsepower actually consumed by the milling cutter in cutting 16 carbon steel.

3 In face-milling much better results are obtained and the difference is ascribed to the lip angle of the cutter used in face-milling. It would appear, therefore, that there is no inherent advantage in face-milling over slab-milling if the cutting edges are alike in each case, and our experiments on slab milling bear out this opinion.

4 In our paper on "The Development of a High Speed Milling Cutter with Inserted Blades for High-powered Milling Machines" presented at this meeting, we would call attention to the very pronounced lip angle obtained by the use of our curved blades, and as far as the actual performance is concerned we have made experiments since that paper was written, through the courtesy of the Niles-Bement-Pond Company, demonstrating that it is possible to obtain with such a cutter from 1 to $1\frac{1}{4}$ cu. in. of 25 carbon steel as against $\frac{1}{2}$ cu. in. of 16 carbon steel obtained by Mr. DeLeeuw. This output is estimated on the basis of 70 per cent for the combined efficiency of motor and slabbing machine and this we believe to be a higher figure than could be established by experiments upon efficiency for such a heavily-geared machine. Probably 60 per cent would be nearer the truth and on this basis the amount of metal removed per horsepower would run from $1\frac{1}{4}$ to $1\frac{1}{2}$ cu. in.

5 Mr. DeLeeuw's experiments were made with a $3\frac{1}{2}$ in. by 6 in. cutter on a machine capable of transmitting 11 h.p., weighing about 6000 or 7000 lb. Our experiments were made with an 8 in. by 18 in. cutter on a machine capable of transmitting 165 h.p. and weighing 70,000 lb. We had, therefore, the advantage of taking heavy chips as well as the advantage of the lip angle referred to, and the limiting capacity of our cutter is not yet in sight.

6 It will be of interest to know that some of these chips (exhibited at the meeting) were removed under more severe conditions than has been attempted in slab milling practice with any type of milling cutter or milling machine. Mr. DeLeeuw states in his paper that the cutter was sharpened before each test. We traversed a steel forging $11\frac{1}{2}$ in. wide and 50 in. long five times without sharpening our cutter and after doing this there was no perceptible dulling of the cutting edges. The first two runs were made at a table advance of $9\frac{1}{2}$ in. and $\frac{21}{32}$ in. depth of cut, and the circumference of the cutter was under approximately 25,000 lb. cutting pressure; the third run was made with a table advance of $5\frac{1}{2}$ in., depth of cut $1\frac{1}{32}$ in., with the cutter under approximately 26,000 lb. pressure, and runs four and five were made with a table advance of $9\frac{1}{2}$ in. per min., depth of cut $\frac{3}{4}$ in. with the circumference under approximately 39,000 lb. pressure, making a total of $30\frac{1}{2}$ min. actual cutting time, in which the cutter traversed 250 in. and removed 607 lb. of steel. The cutting speed in all these tests was 70 ft. per min.

7 In regard to the efficiency of the feed mechanism of the Cincinnati milling machine we are not at all surprised to find it as low as Mr. DeLeeuw has discovered, for the simple reason, that the feed is transmitted through a screw. The efficiency of screws is a matter that has come before the Society and has had very careful consideration. It is well known that a screw is one of the most inefficient mediums for the transmission of power that can possibly be employed. It is nevertheless in many cases the best, but we do not agree altogether with Mr. DeLeeuw that the efficiency of the feed mechanism is a matter of first importance. We believe that the rigidity of the feed mechanism is a matter of more importance than its efficiency. The efficiency can readily be increased by increasing the pitch of the screw. Roughly speaking, the efficiency of a feed screw is measured by the pitch divided by the pitch plus the diameter, and for a screw of $\frac{1}{4}$ in. pitch $1\frac{1}{8}$ in. diameter, such as is used on the Cincinnati No. 3 milling machine, the efficiency should be about 18 per cent. If the pitch were doubled the efficiency would be increased to 31 per cent, and

while better efficiency could be obtained by further increase in pitch, this gain in efficiency, however, would be obtained by the sacrifice of rigidity, inasmuch as the steeper the thread, the greater the tortional strain in the screw and the greater the liability to chatter under heavy work.

Mr. Fred W. Taylor. Mr. DeLeeuw has done admirable work in the experiments which he has described, and work of the kind that is much needed; it is therefore with much hesitancy that I criticise his paper at all, and my criticism is intended to supplement his paper, not to detract from it.

2 His paper gives us facts as to the relative efficiency of three different milling-machines. He has not given us any data, however, which enables us, as engineers, to judge why one of the machines is so much more efficient than the other two. Now in an advertisement, or even in an article written in a technical journal, it is perfectly proper to call attention to the fact that one machine is far better and more efficient than any of the machines competing with it, without giving in detail the reasons. A paper presented to an engineering society, however, should be for the education of its members, and they obtain but little valuable information or education from the mere statement that a result has been obtained, without indication of the exact means by which the result is reached. Engineers want to know not only the result or effect, but also the cause which has produced it.

3 Now the efficiency of a milling-machine is largely the efficiency of its train of driving-gears with the shafts and bearings, plus the efficiency of the cutting-tool. A full description of the trains of gearing, etc., of the three machines should have been given, so that the readers could decide for themselves exactly why one machine is better than the other two.

4 Mr. DeLeeuw of course has this information and I understand would have been entirely willing to present it to the Society if it had been called for by the Meetings Committee or Editor.

5 Again at the end of the paper is a statement which has the appearance of an advertisement. The author states that a new milling-cutter is being patented which is far more efficient than those on the market, without giving even a view of the cutter itself or the slightest inkling as to the cause of this superiority: such a statement should never be permitted in a paper published by an engineering society. I do not think Mr. DeLeeuw is to be blamed for this, but

these facts illustrate the desirability of having a code of directions or advice prepared which shall help the Meetings and Publication Committees in their acceptance and final publication of papers; our editors in their criticism of papers presented; and writers of papers in preparing them for presentation.

Prof. H. Wade Hibbard referred to his earlier enjoyable association with Mr. DeLeeuw in the same designing office and to his own experience with milling machines when learning the machinist's trade in a locomotive-building shop. Going in at 7 o'clock he could hardly get to the high-powered vertical spindle milling machine which he operated because of the large amount of work piled up around it from other machines which ran during the night; but he happened to be one to whom it was a pleasure to see a great amount of metal removed and long before noon the floor was clear. That, too, was before the days of the work of Mr. Taylor or Mr. Gantt, when employees were receiving day wages.

2 One day he twisted off the tool steel arbor of the milling cutter. The foreman looked at the machine and work, saw there was no "bite," smiled instead of upbraiding the operator, and simply ordered him to go to the tool room for another arbor. He then realized that the capacity of the machine had been found and the speaker said that incident might be of interest in the present year of 1908 as showing the capacity of a machine built as long ago as the early eighties, and how its value was recognized by a machine shop contractor.

Prof. J. J. Flather. I wish to add a word of appreciation of the scientific work which Mr. DeLeeuw has done in determining the power required to remove metal by milling and in subdividing that power, placing a portion of it where it belongs, in the feed mechanism.

2 But I wish to protest against the engineer classing "a matter of practical experience, judgment and intuition," as "guess work," as in the first paragraph of the paper. I think that is an engineering estimate and an inference, rather than guess work, and believe this view is really what the author intended. The design of machine tools has been largely based on such estimates in times past, for lack of accurate data, and the engineer has, by a certain process of intuition, and by using his judgment and past experience, put all these factors together, so as to make a very accurate estimate as to what results would be produced under given conditions.

3 The main object of a machine designer should be to produce a tool that will give increased output. The matter of power is of very

little importance. In fact, the cost of fuel in producing power in most of our factories amounts to only two or three per cent, and it does not make a great deal of difference what the power is. What the aim should be is increased output, and any machine that will give increased output, no matter how inefficient it is in the conversion of power, is to be preferred to one that is much more efficient in this regard but has a smaller output.

4 Considering the tools that are in most common use, the lathe and planer and the milling machine, we know, by referring to various tests based on the pound per minute output of metal, that the lathe will remove approximately a pound of steel chips per minute at a cost of 0.4 h.p.; the planer about 2.5 h.p. per pound; and the milling machine approximately 10 h.p. per pound under average conditions. There are so many variables that it is practically impossible to predict how much power will be taken, but the tests show the efficiency of the milling machine to be very low, yet every manufacturer realizes the great saving in labor and time by the use of the milling machine, and the milling machine will be used more and more, because of this saving. This attention to increased output should not in any way prevent us from determining the amount of power required to operate a machine, or its various parts. In fact such tests are often absolutely necessary to a proper handling of the problem; if they lead to a reduction of the power required without interfering with the output, an additional advantage is obtained.

5 The author speaks of the lack of engineering data from which to determine the size of motor to apply to a machine. Today, with the use of high speed steels, this is true to a certain extent, and yet most careful tests have been made, not only to determine the total power required for removing metal and running the machine, but the subdivided power has been determined as long ago as when Hartig was carrying out his experiments in Germany. The experiments showed the amount of power required to run the machine idle, the amount for different speeds, and the amount to remove metal per unit of time. Hartig's experiments included some sixty-nine different machines, with from five to fifty tests on each machine, showing the very wide range of his experiments. Other experimenters, including Vauclain and Halsey, Professor Benjamin, and other members of this Society, have done a large amount of work along these lines, which has been of great value to the designer as well as the user of machine tools.

6 Now, with the advent of the high-speed steel more such experiments are required, and there is a very promising field for some of the research laboratories to take up such problems as have been indicated in this paper, and ascertain how much power is required to operate such machines, and how much may be saved by cutters of different construction, tools of different shapes and different proportions of feed and rate of cutting and various other matters of value to the engineer.

The Author. I would like to go over briefly in chronological order some of the remarks which struck me most vividly. Mr. Miller refers to the milling-machine as a machine especially adapted for tool-room and jobbing work. That has been true almost to the exclusion of everything else. It is true to a very large extent even at the present time, but there seems to be a tendency to use the knee and column type of milling-machine for tool work and jobbing work, for work requiring the fine adjustment to which the milling-machine lends itself, and for work requiring the peculiar feature of the milling-machine, of lending itself to almost any kind of shape one wants to produce; but at the same time the milling-machine is now being used for heavy every-day rough shaping work, plain slabbing, surfacing, etc.

2 One reason why this has not been done in the past may have been the nature of the cutters. It may be that the reason why the milling-machines were used so long almost exclusively for tool-room work was a historical one, but we seem to be rapidly drifting away from this condition; and I thought it would be well, in recognition of this fact, to have some knowledge of the milling-machine outside of its old scope; knowledge of its ability to remove chips. This is not minimizing at all the importance of the milling-machine as a tool-room machine, and I realize fully that the milling-machine may be highly efficient as a machine-tool for a great many lines of work, though it may not be efficient as a user of power. But the milling-machine is also being used more and more for heavy work, and will be used in the future to an even greater extent; and in heavy work an economical user of power is in my opinion very important.

3 I wish to refer also to what Mr. Flather said, that it is not the power that cuts the figure. I would suggest, that we use just as much power as is necessary, and not a bit more, in the machine, and take the rest of the power to drive a fan somewhere in the open air; use the power if you wish to, but do not use it in the machine.

4 The tests which I have described were carried out in order to determine what power is actually required in the machine, and I want to say here, that I realize that these tests are in no sense complete. They have not fully accomplished any of the aims I have set for myself—not even a large percentage; by far the greater part is left undone. It might, perhaps, have been well to postpone the writing of this paper until more complete data were at hand, but the mere fact of bringing this matter up before the Society may assist in starting other people, perhaps better equipped for carrying out such tests, along the same lines, or if they have been working along these lines, may lead them to publish the results of their tests.

5 Mr. Miller further refers to the proportion between the power required for the drive and for feed, and objects more or less to my statement that the pressure against the cutter is practically the pressure against the table. I mentioned this, but with certain limitations, and it may be that the limitations were not put clearly enough. All the cuts taken during these tests were what might be called flat cuts; relatively wide and of little depth; the depth of the cut as compared to the diameter of the cutter was small, and for that reason the upthrust was not very large; and even under these conditions it is not quite true that the thrust against the cutter is the same as that against the table. This is not mentioned in my paper as a fact, but merely as the supporting argument which led up to my realizing the desirability of making some tests on feed efficiencies.

6 I appreciate the remarks made by Mr. Wilfred Lewis in regard to the heavy chips taken by his heavy cutters. I have had some connection with concerns making heavy machines, and have previously spent some time in shops where these heavy machines were being run, on steel, and taking extremely heavy chips. A heavy chip will make me walk around several squares; but the machines I had to deal with would not allow taking such a chip as can be made with a 165-h.p. motor. However, though the tests described do not give any information as to the efficiency of the larger machines, the horse power used on all of the knee and column type machines is, I believe, very much larger than on all of the heavier type of machines on which Mr. Lewis made his tests, and for that reason I believe I do not need to apologize for having limited my paper to the smaller machines. Perhaps the size is not there, but the quantity certainly is.

7 As to the necessity of regrinding the cutter after each series of tests, I may have given the impression that this was necessary, because

the cutter was pulled off after each series of cuts. This was not the case, however. The cutter was reground merely to start every series of tests under the same conditions, and to make the tests on the different machines as nearly uniform as possible.

8 Referring to Mr. Taylor's desire to have causes given as well as effects, in other words to have it shown why one milling-machine should be more efficient than the other, I wish to refer him to the title of my paper, which is not "Efficiency of Milling-Machines" but "Efficiency-tests of Milling Machines:" it is not therefore supposed to give a clear account of everything pertaining to the efficiency of milling-machines, but merely an account of tests made, the methods employed and some of the results obtained; with here and there a guess as to the possible cause. I realize that a complete treatise on the efficiency of milling-machines would be of great interest, but confess that I have not sufficient data for even the foundation of such a treatise. If all the different makes of milling-machines had been tested and one particular make found superior in efficiency, and if this fact had been mentioned in my paper, some statements about the probable cause certainly would have been in order: only four machines have been tested, however, and the result can be of interest only as it shows that a difference in efficiency exists.

9 I believe this paper meets the requirements set up by Mr. Taylor, namely, that it should be of some educational value to the members of the Society, though I realize that it is that only to a very limited extent. Yet the aim of the paper was, by bringing forward methods employed in testing milling-machines, to enable others to work along the same lines, and to whatever small extent this aim has been accomplished, to that extent my paper must have educational value.

10 I am very much puzzled by Mr. Taylor's remark that my statement as to the new milling-cutter has very much the appearance of an advertisement. It would seem to me that to mention that a milling-cutter exists, but not to describe it, nor to show a picture, nor to say who makes it, nor even that it is being made or ever will be made, lacks about all the essentials of a live advertisement.

11 On the other hand I fully agree with Mr. Taylor as to the desirability of having prepared a code of directions or advice, which shall help, among others, the writers of papers to be presented.

FUEL ECONOMY TESTS

By C. R. Weymouth, Published in The Journal for Mid-November

ABSTRACT OF PAPER

In this paper are presented results of tests at the 15,000-kw. power plant of the Pacific Light and Power Company, Redondo, Cal., having steam engine prime movers, crude oil being used as fuel. The fuel economy is stated for tests on a 5000-kw. plant unit at various uniform loads, approximating 2000, 3000, 4000 and 5000-kw.; on a variable railway load; and also for the entire station on a similar variable railway load. The operating and test conditions are fully described.

The results given indicate a remarkable plant economy under all conditions, but the particularly striking feature is the almost uniform fuel economy for the plant unit for all fractional loads from about one-half load up to the maximum load tested. The author believes that the results warrant a careful investigation as to the possibilities in the line of superior plant fuel economy, using the more modern types of steam engines as prime movers.

UNNECESSARY LOSSES IN FIRING FUEL OIL AND AN AUTOMATIC SYSTEM FOR ELIMINATING THEM

By C. R. Weymouth, Published in The Journal for December

ABSTRACT OF PAPER

For a long period engineers have attempted to solve the problem of automatic firing of steam boilers in plants burning liquid fuel. The writer presents, as a solution to this problem, an automatic system of regulation, explaining its development and details of construction, and also its application and successful operation at the Redondo plant of the Pacific Light and Power Company.

An oil pump governor actuated by variations in the boiler steam pressure so varies the oil pressure in a common oil main, and accordingly the simultaneous rate of firing in all burners, as to maintain

practically uniform steam pressure at boilers. This variation of pressure in the oil main is the secondary means for controlling the supply of steam to the burners for purposes of atomization, and also for controlling the amount of damper opening, and thus the air supply for combustion.

Due to this automatic and synchronous adjustment of all the functions of the boiler and furnace, there results on plants subject to fluctuating load an increased boiler economy, which is due to the more uniform rate of firing, the saving in steam used for atomizing the oil and the reduction to a minimum of the air supply for combustion.

DISCUSSION

Mr. Geo. H. Barrus. The author states in the first paragraph that this plant gave a "notable economy," which means, I suppose, that it gave a better economy than other large electric steam power plants. It would add much to the value of the paper if he would present examples of what has been accomplished by other plants, so that we could see to what extent the economy shown is really notable.

2 It would also be interesting, and of great value, if he would tell us something about the economy of the individual elements of the plant, i.e., what was the efficiency of the boilers taken by themselves; also what was the steam consumption of the engines per i.h.p. per hour. With information of this character, the members of the Society would be able to form some idea themselves as to whether the plant was economical. Upon this subject there is no intimation in the paper as presented.

3 It seems to me highly improbable, in connection with a test of such a character as the one described, involving, as the mechanical papers have told us, such a large pecuniary bonus, and one which required the assistance of such a large corps of testing men as the number referred to, that some one did not make an evaporative test of the boilers, and steam consumption test of the engines, to determine their individual economy. Very likely the author has such data, and I will be glad to hear from him on that point.

Prof. William Kent. The papers are very interesting as showing what can be done with oil and with reciprocating engines on the Pacific coast. The statement in Par. 68 of the paper on Fuel Economy Tests, that "Inasmuch as the steam turbine gains largely in apparent economy due to increase in vacuum, similar reductions should be made in the stated economy of such plants, and correspond-

ingly in the reported fuel consumption," indicates that the author considers the result of the test a proof that reciprocating engines are as good as turbine engines; and seems to be equivalent to saying it is believed that the steam turbine is good because it can utilize a high vacuum, which the reciprocating engines could not do economically: and that for this reason we must deduct from the economy of the turbine the amount it gets from the high vacuum and charge that against it. I do not think that is fair to the turbine.

2 These tests show very good results in kilowatt-hours per barrel of oil. Between the barrel of oil and the kilowatt-hours there are many variable conditions. First, there is the oil-burner. I understand that they have in San Francisco a new burner which is more efficient, especially in the regulation of the air supply. It appears that part of this higher economy in the San Francisco test is due, not to extraordinary efficiency in heating surface of boilers, but to the regulation of the air supply. Second, the efficiency of the boilers in San Francisco is due to the theoretical fact that it is possible to get a greater percentage of efficiency out of oil than out of coal. I know of no large plant in the East tested with oil. We have to test with coal, where we are troubled with ashes, the large excess of air necessary to burn coal properly, and many disadvantages which the writer would credit to the coal pile, because it suffers these disadvantages.

3 Thus we have in favor of oil, the theoretical economy higher than that of coal and the diminution of the excessive losses due to unregulated air supply in coal firing. The records of the test fail to show, however, how much of the total economy between kilowatt-hours and barrels of oil is due to the reciprocating engine. As far as I can find, not a single point is made in favor of the reciprocating engine, other than the general statement that because we have the great economy the reciprocating engine is a good engine.

4 In making a test between the reciprocating engine with oil as fuel under the boilers, and a turbine engine with coal, we have so many variables that from such a test-record a statement of the relative value of the reciprocating engine and the turbine is impossible. The only way to get such a statement is to have a test made with the turbine in San Francisco with oil, with the same boilers and with same adjustment of air supply, and Professor Jacobus to watch it, and we will get as good results out of the turbine, if not better, than have been obtained from the reciprocating engine.

Prof. William D. Ennis. It is difficult to say whether in reality this plant is showing notable economy. A heat consumption of 25,228 B.t.u. per kw-hr. is perhaps unprecedented, if it is maintained in the ordinary operation of the plant. This rate, noted during the 15-day test, under expert superintendence, is, however, not comparable with the 2 to 2½ lb. coal consumption rates of our best large plants day in and day out as the load factor comes. It is to be regretted that the details of the boiler performance are not given, as this would permit of judging as to the economy of the engines. Assuming that the boiler efficiency was 0.80, and the efficiency from engine cylinder to switchboard 0.855, then the heat unit consumption from line 24 of Table 1 was about 215 B.t.u. per i.h.p. per min.—not at all an exceptional result with superheat, under test conditions

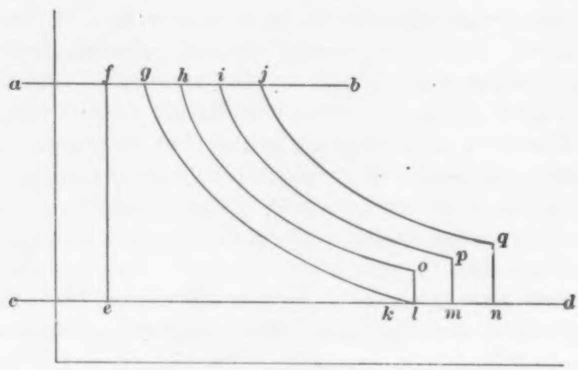


Fig. 1 Comparison of Rankine and Clausius Cycles.

With engines of this size, operating at 180 lb. pressure, and with certainly a fair vacuum—28.334 in.,—one would almost expect a better result. If these were service tests, however, then the results are of course most excellent. But the results do not seem to be those to be anticipated in regular running.

2 The proposal to compare engine performances with the limits possible in a standard cycle has been made before. There is no good reason for calling this standard cycle that of Rankine. It is true that Rankine recognized that the terminal pressure might be *equal to*, greater than or less than the condenser pressure (*The Steam Engine*, 1897, Art. 278); but all of his computations are based on the existence of some terminal drop. On the other hand, Clausius (*Fifth Memoir, On the Application of the Mechanical Theory of Heat to the Steam*

Engine) clearly describes what I suppose we have all had in view as the standard cycle; viz, one in which adiabatic expansion is followed by isothermal condensation without intermediate drop in pressure. The expression for efficiency of this cycle is perfectly definite, based on the upper and lower temperatures: that for the Rankine cycle is not. The illustration may make this clear. The Rankine cycle between the limits *a b* and *c d* might be any one of *fjqne, fipme* or *fhole;* the Clausius cycle can be only *fgke*.

Mr. J. R. Bibbins. Much information of an important character has been omitted from this very interesting and valuable paper; namely, data on individual efficiencies of engine and boiler plants respectively. It may have been difficult to obtain such data during the test, but they are certainly essential to the conclusion reached by the author, whereby the reciprocating engine is credited, by inference if not directly, with the major part of the excellent results obtained although no data are presented which give the least possible ground for such a conclusion.

2 Suppose, however, we take the author at his word and compute the efficiency possible from a steam motor working under the precise conditions stated. Referring to the 15-day test, the average load was about 3660 kw., and it is stated that the engines were rated at 4000 kw. Presumably, therefore, the engines during this 15-day test were operated at approximately their point of best economy. Now on the other hand, consider a turbine plant similarly rated at or near its point of best economy (just before the overload valve comes into service). If we supply this turbine with steam at 180 lb. pressure, 82 deg. superheat and a vacuum of 28½ in., or even 28 (allow for drop between condenser and turbine), it is a question whether the author would place his opinion on record that the economy thus obtained in connection with the same oil-burning boiler plant would be inferior to the corresponding economy obtained by test on the reciprocating engines. In other words, with a given boiler plant and given conditions of operation, does the author claim for the reciprocating engine economy superior to that which recent tests of large turbines have demonstrated beyond reasonable doubt? This is to be inferred from his closure. In Par. 68, the author states that, "inasmuch as the steam turbine gains largely in apparent economy due to increased vacuum," the reported economy from turbine plants should be reduced accordingly for comparison with engine-driven plants. The vacuum reported in the Redondo tests is fully

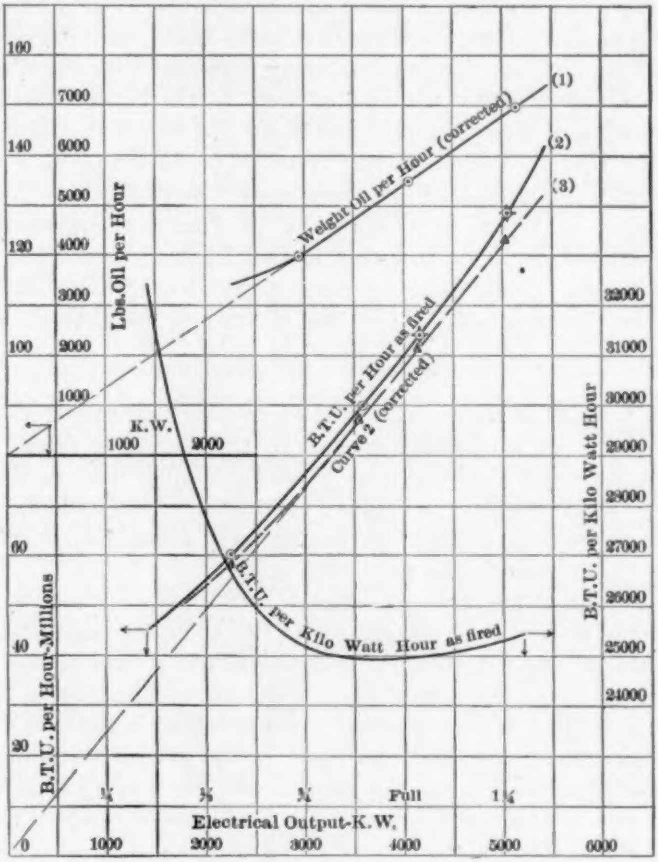
as high as is obtainable in the best turbine plants in the country —28 and 28.4 in., therefore the necessity for correction is not apparent.

3 The crux of this whole matter seems to be the efficiency of the boiler plant with oil fuel. Three years ago the United States Naval Bureau of Steam Engineering conducted extensive tests with both oil and coal fuel upon a marine water-tube boiler, with the specific purpose of ascertaining the comparative boiler efficiencies respectively obtainable. Detail figures are not at hand, but the average ratio of evaporation between coal and oil, under otherwise identical conditions, was in the neighborhood of 10 to 15; and under normal power-plant conditions of land practice, the ratio was reported still higher, 10 to 17. Correcting for the difference in heat-values of fuel burned, it is apparent that the efficiency of an oil-fired boiler plant is from 10 to 20 per cent higher than that of one burning coal.

4 Assuming then a turbine plant generating a kilowatt-hour on 15 lb. of steam, under the conditions obtaining during the Redondo test, and a boiler plant burning coal with the efficiency of an oil-fired plant, evaporation would be at least 10 lb. of water per pound of coal, and the overall fuel consumption 1.5 lb. per kilowatt-hour or 21,000 B.t.u. per kilowatt-hour, an economy superior to that obtained at Redondo. That the turbine economy above noted is quite conservative is apparent from the results of tests upon a large turbine at the Waterside Station of the New York Edison Company. An average economy better than 15 lb. was obtained under conditions of 175 lb. pressure, 96 deg. superheat and 27.3 in. vacuum. It does not seem, therefore, that the reciprocating engine has demonstrated itself in the Redondo tests capable of any extraordinary economy, *per se*.

5 The shape of the economy curve *A*, Fig. 3, seems to establish a rather novel load characteristic for a power-plant unit; viz, practically constant economy over an extraordinary range of load. If we consider the reciprocal of this curve in pounds of oil per kilowatt-hour, and again convert this into total oil per hour plotted against load, we have a so-called Willans line, shown as curve 1 of the accompanying figure. This Willans law is highly valuable in analyzing the rational performance of both steam and gas plants, and at a glance indicates unusual results. In this case, the load-oil consumption curve is practically a straight line from the origin above about 3000 kw., curving rapidly below this point, a phenomenon for which

it is difficult to find a good explanation. If now we plot a similar Willans line for load B.t.u. per hour, taking the observed values (line 24, Table 1), curve 2 is obtained. This line of total heat consumption appears entirely rational as a characteristic of a steam engine governing by cut-off. It shows a decided curvature, the relative heat consumption increasing on both heavy and light loads.



The point of tangency of a radial line from the origin indicates the point of best economy to be in the neighborhood of 4000 kw., which is entirely rational.

6 Finally, if the values obtained by correcting oil consumption according to contract stipulation are plotted (line 23, Table 1), the

Willans line flattens out into the straight line 3, above 3000-kw. load, but shows an even more marked curvature below this load. This would indicate a practically constant heat consumption of the unit from 3000 kw. up.

7 The reasons for these peculiar characteristics are not clear, and from the known characteristics of a reciprocating engine tested at different loads, as was done in this case, it may only be inferred that the reasons lie in a variable boiler-plant efficiency. To my knowledge there is no prime mover possessing a straight-line characteristic through the origin, i. e., an economy remaining constant with the change of load. Consequently, we may look only to the boiler plant for an explanation of these results. And it is to be hoped that the author may be able to submit further data. The Redondo tests are so thoroughly authenticated in every respect as to preclude the usual possibility of errors of observation, so that the opportunity is exceptionally good for throwing further light upon oil-fired boiler performance. This would be particularly desirable in connection with the discussion of the methods of firing in the author's second paper.

Mr. I. E. Moultrop. This is an interesting paper upon a subject which has been somewhat neglected by the Society in recent years, and in the writer's opinion more papers on similar lines would be of value. Mr. Weymouth has made a careful test of the Redondo plant, and is to be congratulated on having built a fine station and one which shows remarkably good economy.

2 In view of the care with which this test was made and the large number of trained observers employed, it is to be regretted that more information was not obtained at intermediate points in the cycle which would point out specifically how this fine economy was obtained. There is nothing to show whether it was obtained in the boiler plant, the engine plant, the condenser plant, or the general station design. The author apologizes for the vacuum and attributes the lack of a better one to the temperature of the cooling-water, which he considers high. The vacuum seems to be remarkably good under the given conditions, however.

3 Mr. Weymouth is in error when he states that Eastern power stations obtain their higher vacuum only by the use of cooling-water at a temperature near the freezing point. The writer knows of a number of large power stations where the condensing apparatus is designed to give vacuums inside of 1½ in. absolute with the circulating

water from 5 to 10 deg. higher than the temperature stated in the paper; and he is inclined to think that a material increase in the cooling surface of the condenser, other conditions being the same, would have considerably improved the vacuum in this instance.

4 Some of the conclusions drawn by the author seem unwarranted, especially where he unfavorably compares large turbine stations in the East to his station. There is nothing in the paper which justifies the assumption that the engineers did the best thing when they selected steam engines for the prime movers. As the superior economy of steam turbines over reciprocating engines as prime movers for electrical generating stations has been so well demonstrated, and as the vacuum carried on the plant during the test was not especially good, only the boiler plant is left to be considered in accounting for the good results obtained. Tests in other places, and notably by the United States Geological Survey, indicate that boilers fired with good fuel oil show a considerably higher economy than with first-class steam coal.

5 The central station manager naturally wants a generating plant which will show a fine performance on the B.t.u. basis, but he is much more concerned in having a generating station which will put the maximum of kilowatts on the switchboard for a dollar spent in operating; and while the geographical situation of the Redondo station was doubtless such that fuel oil was a wise choice, no cost-information is given, and there is therefore no means of determining whether or not an engineer in the middle or eastern states would be justified in building a station for the use of fuel oil.

6 There is one point in the operation of this station which the author has not touched, and which I hope he will include in his closure, and that is the matter of the successful removal of the cylinder lubrication from the condensed steam before it is returned to the boilers. This has been a very serious objection to the use of surface condensers with steam engines in power plants, and it would be extremely interesting to know, either how the oil is successfully removed or what difficulties and extra expense are entailed in operating the plant by reason of more or less oil getting in the boilers.

Mr. A. H. Kruesi. The subject has been well covered by those who have already discussed the paper. The economy hinges on the efficiency of the boilers. It appears that the conclusions on the last page are hardly justified without more data as to where the economy of the plant is to be found. The boilermakers might claim a

large part of the credit and as has been shown a large part of it is due to the use of a fuel which is little short of ideal. It can be controlled instantly, produces very little flue dust, and has many other advantages which need not be detailed here.

2 It may be noted that the conclusions as to the flexibility of these units make a virtue of a necessity of the steam engine. By the same argument it might be contended that it is desirable to use five 1000 kw. turbines, instead of one 5000 kw. turbine, to reduce the liability of breakdown and increase flexibility of operation.

Mr. F. W. O'Neil. The paper upon Fuel Economy Tests is of value in showing the performance of engines at fractional loads. As pointed out in Par. 58 the losses are proportionately greater at fractional loads, yet as the difference in losses at full and fractional loads is relatively small, the economy of the engines fairly approximates the economy of the whole station.

2 The result obtained of 252.8 kw.-hr. per bbl. of oil, or 25,288 B.t.u. per kilowatt hour, is by no means extraordinary when compared with the performance of engines reported to the Society in the past and when the size of the plant, the high vacuum and superheat are taken into account, as well as the high boiler efficiency possible when firing with oil.

3 The thing which is extraordinary in this report is the low guarantee accepted by the purchaser of 170 kw.-hr. per bbl. of oil, especially when it is considered that a large bonus was to be paid for every kilowatt hour secured over and above this amount. The difference between the guaranteed economy and the economy obtained on test is 32.8 per cent, or, in other words, the plant used 32.8 per cent less fuel than would have been consumed had the actual economy corresponded to the guarantee. This fact, together with the conclusion of the writer, might lead some to believe that the difference between the guaranteed and obtained economy represented the accuracy with which designing engineers were able to predict engine performance. The writer believes it desirable to call attention to the fact that the above difference is by no means a fair measure of the ability of steam engine designers to predict engine performance.

4 It is to be regretted that water was not weighed, or, if it was, that the amount was not included in the results, so that the separate performance of boilers, engines, etc., could be segregated.

THE TRANSMISSION OF POWER BY LEATHER BELTING

By Carl G. Barth, Published in The Journal for January

ABSTRACT OF PAPER

This paper offers an advanced theory for the transmission of power by leather belting, and mathematically takes account of a number of facts brought to light years ago, but never before fully explained or utilized in belt formulae. It also presents, in practical working diagrams, the results obtained by numerical substitutions in the formula developed, and illustrates a slide rule on which almost any practical question relating to the transmission of power by leather belting may be quickly solved. The complete paper consists of a main body setting forth the leading results and conclusions; an appendix containing the leading features of the mathematical work; and an unpublished supplement, on file with the Society, to which have been relegated the details of the mathematical work, as well as some additional conclusions, refused publication in the paper.

DISCUSSION

Mr. Henry R. Towne. The earliest investigation of this subject was by General Morin, of the Conservatoire des Arts et Métiers, who gave, in a volume published, I think, about 1850, the results of his experiments to determine the co-efficient of friction of belts on pulleys, and algebraic formulae to express the power transmitted under varying conditions. For many years these formulae were accepted universally. General Morin's experiments were made under laboratory conditions.

2 In 1867 I made a series of experiments to determine, under conditions approximating those of actual use, the co-efficient of friction and also the tensional strength of commercial belting. These experiments, and a discussion by the late Robert Briggs on the mathematical conditions involved in the problem, were published in the Journal of the Franklin Institute in 1868. Under the title of

the Briggs and Towne Experiments, the conclusions thus reached were quoted and accepted for many years, by Professor Rankine, Professor Reuleaux, Professor Unwin, and many other technical writers. Mr. A. F. Nagle, in a valuable paper contributed to the Transactions of the A. S. M. E. in 1881 (Vol. 2, p. 91), accepted the results of the Towne experiments as the basis for his discussion of the mathematical problems involved.

3 The Transactions for 1886 (Vol. 7) contained two important contributions to the literature on this subject. One of these is a paper by Professor Lanza (p. 347), which first prominently calls attention to the importance of *speed of slip* as a factor in the transmission of power by belting. The other is a paper by Mr. Wilfred Lewis (p. 549) giving the results of a long and elaborate series of experiments in the shops of William Sellers & Co., and demonstrating, among other things, that the proposition first enunciated by General Morin, and accepted unquestioningly by all subsequent authorities, namely, that *the sum of the tensions is constant* ($T_1 + T_2$), does not hold true in all cases, and is therefore erroneous.

4 The Transactions for 1894 contain another most valuable paper, by Mr. Fred W. Taylor (p. 204), giving the results of his large experience covering many years in the use and observation of belting under the conditions of actual practice. Many new and important deductions from the investigations of Mr. Taylor are summarized in this paper and in the writer's discussion of it (p. 238). Mr. Taylor's most important deduction effected a departure from the long accepted assumption that the co-efficient of friction is constant, to a recognition of the fact that it *varies with the tension per square inch* (or other unit of area) of the belt, and hence that there is substantial advantage and economy in the use of thicker belts. He was also the first to demonstrate and set forth clearly the economic gain to be derived from the scientific care of belting.

5 Finally, Mr. Carl G. Barth, availing himself, as he has stated, of the work of his predecessors, especially that of Mr. Lewis and Mr. Taylor, has completed, for the present at least, the study of this problem, which has thus extended over some sixty years, giving us an elaborate and apparently a conclusive demonstration of the soundness of the mathematical conclusions finally reached, furnishing *working formulae for practical use*, and presenting a most ingenious application of the *slide rule* to the problems involved in the practical use of leather belting.

6 The Society is to be congratulated on including in its roster of

membership the names of all those since General Morin who have taken the lead in ascertaining the facts and in determining therefrom the rules which govern the application of leather belting to industrial uses.

7 Mr. Barth's system has now been in use for about two years in the works of the Yale & Towne Mfg. Co., Stamford, Conn., where it has accomplished a substantial increase in economy and efficiency.

Mr. Wilfred Lewis. It is only by carefully conducted experiments and careful analysis of the underlying principles involved, that substantial progress can be made in the field of engineering; and I am clearly of the opinion that Mr. Barth has discovered and formulated principles of the greatest practical value in the solution of the problems of the transmission of power by leather belting.

2 It is difficult in a paper of this kind to separate the practical from the theoretical without discarding the most valuable part of the undertaking; the laborious work done by the author in order to reach his conclusions, and recorded in the appendix to this paper, is really the basis of the superstructure reared by him and gives the reader some idea of the immense amount of patient research and good sound reasoning employed in building up a complete analysis of the subject.

3 Mr. Barth is the first, I believe, to analyze the peculiar elastic properties of leather, and to demonstrate in a convincing way the effects of these properties in the use of belting under varied conditions. His analysis of the combined effects of elasticity and sag is very original and ingenious, and even aside from the results obtained his methods cannot fail to interest investigators in other fields of research. Difficult and complex problems have been solved by making certain assumptions and approximations that are quite allowable as the means to an end, and it is in these short cuts from the intricate and unwieldly to the simple and practical that he has displayed such remarkable ingenuity. At the same time, for those not enough interested in every step to care to follow a mass of mathematical formulae, Mr. Barth has presented his conclusions in a form available for immediate use.

4 Popular impressions, even though well founded, are often exaggerated beyond reasonable bounds, and while it is true that horizontal belts of considerable length are preferable in the transmission of power to vertical or shorter ones, it will be a surprise, I believe, to engineers, that there really is so little advantage in a

long horizontal belt over any length of belt in any position. All this results from the exposure of the fallacy that the sum of the tensions is constant, a belief exploded 23 years ago, although the far-reaching effect of the exposure on the transmission of power by belting has never before been so clearly expounded.

5 The author's treatment, also in the unpublished supplement to the appendix, of the effect of variations in pulley diameter upon the transmission of power, I believe to be absolutely original, and his conclusion that a belt will slip on a driven pulley before it will slip on a driver of the same diameter indicates a subtlety of analysis rarely displayed in our proceedings, and is a fair index of the painstaking care with which the whole paper has been written. Although not perhaps of very great practical importance, as a new discovery, the analysis might well be included in the appendix to the paper rather than in the unpublished supplement to the appendix.

6 It is safe to say that in the slide rule, engineers who wish to make the best use of leather belting will have at their command an instrument capable of solving at once many problems that might otherwise consume a good deal of valuable time.

Mr. W. D. Hamerstadt. A number of highly valuable papers have been presented before the Society from time to time, dealing with the subject of belt transmission, which have, in the main, contributed only to our better understanding of specific problems involved; it has remained until the present time for someone to assemble the results of such former efforts into a final perfected theory, as has so admirably been done by Mr. Barth.

2 For several years past, the writer has been somewhat closely associated with work on pulley and belt drives, and recently has had occasion to compare the results of some carefully conducted experiments with the results which might be expected from the use of formulae as proposed in Mr. Barth's paper. Considering the many variable factors, these comparisons are remarkably favorable, and for average conditions of operation, the relationships which have been established would appear to hold quite true.

3 One almost vital point of consideration in the actual design of belt drives seems to have been touched upon but lightly, however, and then in a manner which, as the author himself has stated, leaves some room for discussion—namely, values of the coefficient of friction to be used in the formulae given, under varying conditions of service. While the value of the coefficient of friction will not affect

the theory of belt transmission as given, it will seriously affect the size of drive required to do a given work, and having now a good theoretical basis for work, and assisted by the observations of others, additional experimental work might well be done for the determination of such values, using as nearly as possible good average leather belting and operating under actual conditions of service.

4 Based partly on the conclusions of Professor Lanza or of Mr. Wilfred Lewis, as given in early papers before the Society, and partly on the very mechanical reasonableness of the thing as he puts it, Mr. Barth assumes that, given a belt and pulley, the value of the coefficient of friction to be used in any case will be determined to a great extent by the velocity with which the belt slides on its pulley. Taking then a curve representing average relations between these two factors for any convenient speed of belt, values are at once available for the coefficient of friction for any speed of belt and any condition of slip desired.

5 That there exists some ground for such reasoning cannot be denied, but a brief comparison of results actually obtained from tests performed from time to time, on belts operating at widely different speeds of service, leads one seriously to question its application to practice. Such comparisons rather lead one to expect more nearly correct results when drives are designed on the basis of relative slip between belt and pulley.

6 Fig. 1 and Fig. 2 show a series of curves representing, for a number of different tests, the relation existing, first between values of the coefficient of friction and velocity of slip, and second, between values of the coefficient of friction and percentage of slip. Information regarding the data from which these curves were plotted is given in the table. Letters designate corresponding tests in either set of curves.

7 Referring to Fig. 1, it will be noted that for each different speed of belt there appears to exist a clear and well defined relation between values of the coefficient of friction and velocity of slip; at lower velocities of slip more especially, the value of the coefficient appearing to be higher for slow-speed belts and lower for high-speed belts. Obviously then, any curve representing a relation between values of the coefficient of friction and velocity of slip holds true only for that speed of belt for which it is plotted and cannot be used indiscriminately for all speeds of belts. The effective range of velocities of slip which would be used in the design of belt drives would probably be from 0 to 25 ft. per minute, as indicated in Fig. 1, and the error

which might be incurred then in using either of the extreme outside curves shown (even though they do not represent maximum possible range of speeds of belts) would vary from about 70 per cent to values almost infinitely large. The curves B_1 and C_1 indicate the relation that would presumably have held true between values of the coeffi-

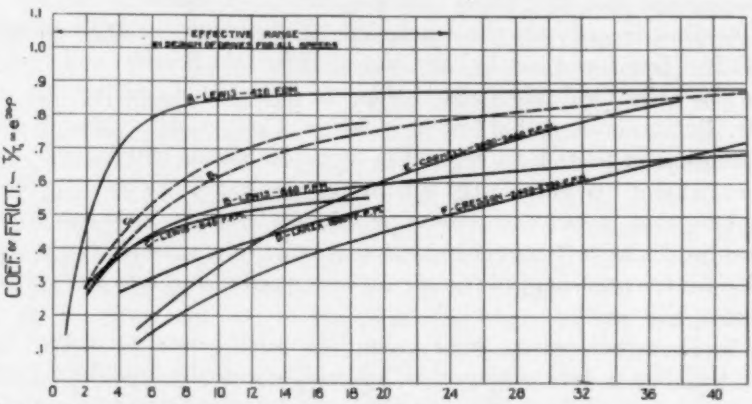


Fig. 1 Relation Between Coefficient of Friction and Velocity of Slip

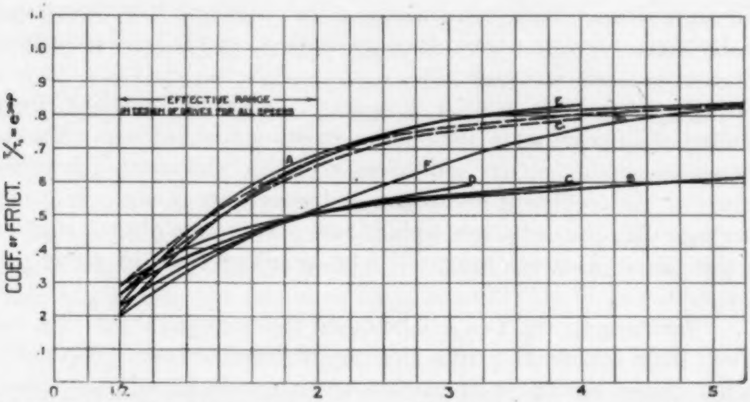


Fig. 2 Relation Between Coefficient of Friction and Percentage of Slip

cient of friction and velocity of slip for belts B and C had those belts been such as to have shown a maximum value of the coefficient equal to that of belts A, E or F.

§ 8 From Fig. 2 it will be noted that for any given speed of belt the same general relation between values of the coefficient of friction and per cent of slip appears to hold true, and belt drives designed on

such a basis might then reasonably be expected to give anticipated results at all speeds of operation. When curves B_1 and C_1 are plotted to represent higher values of the coefficient of friction for belts B and C, as in Fig. 1, the similarity in form of these curves is remarkable —the more so as they represent tests performed in some cases over twenty years apart.

9 But it is not the intention of the author to attempt to establish at present a positive basis of determination of changes in the value of the coefficient of friction. It is hoped, however, that certain proposed experimental work having as its object the determination of such a basis will shortly be undertaken; and results of such work might be presented to the Society later. In its present connection, the manner in which changes in the value of the coefficient of friction occur is a matter of some importance and the seeming fallacy of the present accepted theory appears worthy of further consideration.

10 As an example of the results to be expected when drives are designed on the basis of velocity of slip of the belt, as proposed in the paper, let two extreme conditions of service be taken. one a drive operating at a speed of 400 ft. per minute and at a slip of about 2½ per cent, the other a belt operating at a speed of 5000 ft. per minute and at a slip of about 1 per cent. The slow-speed belt would then have a velocity of slip of 5 ft. per minute on each pulley, the high-speed belt of 25 ft. per minute. Referring to Fig. 7 in Mr. Barth's Appendix, it will be found that for such velocities of slip the values of the coefficient of friction to be used should be respectively 0.38 and 0.53; but the maximum value of the coefficient of friction at even the highest velocities of slip of 60 ft. per minute, as shown, is only about 0.57 and it appears then that the overload capacities of all drives is limited to about that value. This amounts, in the case of the slow and high-speed belts given, to about 50 and 7½ per cent respectively.

11 It is safe to say, however, that fully 80 to 90 per cent of all high-speed drives are used in connection with electrical machinery, and for such work drives must have an overload capacity of at least 50 per cent of their rated capacity. It would be necessary then, for such practice, that belts be originally designed for correspondingly lower velocity of slip, amounting in this case to a velocity of about 5 ft. per minute. The high-speed belt, noted above, at ordinary conditions of service would then operate at a relative total slip between pulley and belt of only one-fifth of one per cent.

12 While the author has had occasion to observe a large number

TABLE 1 DATA USED IN MAKING COMPARISONS SHOWN IN ILLUSTRATIONS

Curve	Test	Speed of Belt Ft. per Min.	Belt			Pulley		Remarks
			Kind Leather	Size Inches	Condition	Kind	Diam. Inches	
A	Wilfred Lewis: Table 4, Exp. 209–259	420	Oak-tanned Double	4 x $\frac{5}{16}$	New, Dry and Clean	C. 1.	10	Belt Run under Severe Conditions, Tests made to Determine Point of Slip at which Belt Leaves Pulley.
B	Wilfred Lewis: Table 1, Exp. 60–75	840	Single	5½ x $\frac{7}{32}$	Old, Good and Pliable	C, 1	20	....
C	Wilfred Lewis: Table 2, Exp. 105–135	840	Double	2¼ x $\frac{5}{16}$	Old Dry and Clean Quite Pliable	C. 1.	20	....
D	Prof. Lanza: Vol. 7, Trans. West Belt, Exp. 1–11	1500	....	....	....	C. 1.	......	$T_1 + T_2$ Assumed Constant and Corresponding Error Made in Calculated Results.
E	Cornell University: Exp. 1–82	2000–2400	Oak-tanned new, single	5 x $\frac{3}{16}$	Dry and Clean	C. 1.	24	
F	Geo. V. Cresson Co.: Catalog B, 1906, Exp. 1–100	2400–2700	New, single	3 x $\frac{5}{16}$	Dry and Clean	C. 1.	24	Tests made at Cornell University

NOTE: All of the belts given were in good working condition when tested, being free from oils, grease or dressings. Belts B and C had been subjected to more or less oil in service before testing, however, which accounts in part for lower relative values of their coefficients of friction.

of successful high-speed drives on electrical machines, just the condition of slip here indicated has never been noted, but in almost every case the overload capacity of the drives has been noted as a function of the relative slip between belt and pulley.

13 When it is further considered that, generally speaking, the point at which the belt will leave its pulley is a function of the per cent of slip and is taken independent of the speed of belt, it certainly appears that the relative slip cannot but play an important factor in determining values of the coefficient of friction to be used for such drives.

Mr. Fred. W. Taylor. The first thought of many of our members on seeing a paper on Belting is, Why should a paper on this subject be presented to our Society? With the advent of the electric drive, is not belting so rapidly becoming a back number that a paper on this subject will arouse but little interest? Certainly, judging of the comparative value of the belt drive and the electric drive by the relative number of papers written on the two subjects of late years, one would conclude that the belt drive is worthless. The electric drive, however, is a new element in engineering and one in which progress has been both rapid and sensational, while the average engineer has concluded that but little new remains to be known about belting.

2 The belt is one of the oldest and most commonplace of the elements used in shop practice, so that engineers designing new establishments or remodeling old ones, who wish to be up-to-date, naturally incline toward the use of the electric drive rather than the belt. There is no doubt, however, that this has led to the use of the electric drive in many instances where the belt would be far more economical and satisfactory in almost every way.

3 In the average machine shop, for instance, the writer is prepared to say that for more than half of the machines the belt drive can still be used with greater economy and with more satisfactory results than the electric drive; only on the assumption, however, that the belting is systematically cared for. The most serious objection to the belt drive as generally used is the loss of time due to interruption to manufacture when retightening and repairing, and to the loss of driving power and consequent falling off in output, when the belt is allowed to run too slack. Belts can be tightened and repaired at regular intervals after working hours, however, with the use of spring-balance belt-clamps to get the right tension, causing thus practically no interruption to manufacture.

4 As will be explained later, it has been shown by an accurate record kept through a long term of years, that in the average machine shop the average cost per belt per year is $2.25. This includes the original cost of the belt, plus all labor and materials used in maintaining, repairing and cleaning it throughout its life. No similar statistics for the maintenance and renewal of the motor drive seem to be available, but I think no one will contend that the latter can in any way approach this economy.

5 In a great number of cases the electric drive should be used in the machine shop, but in the writer's judgment the burden of proof still rests on the motor drive to show in each case that the economy in delivery and removal of work more than makes up for the extra cost of installation and maintenance, and for the delays incident to repairs, blowing out fuses, etc. In large machines economy lies on the side of the motor drive in many instances, but with almost all small machines the belt drive should still be used. In view of these facts, the belt drive is hardly a back number. In fact, the manager of one pulley manufactory told me recently that even during the dull times his company had been selling from twelve to fifteen thousand pulleys per month.

6 Under the rules still in common use, a large proportion of belt drives are badly designed, and belts are used under heavier tensions than they should be for all-round economy. Therefore there is ample justification for a paper such as Mr. Barth's. All who have experimented with belting or who have been interested in the mathematics of belting, will be filled with admiration at the remarkable analysis which Mr. Barth has made of this difficult problem. Even Mr. Lewis, whose experiments and scientific conclusions have properly been given first place among writings on this subject, tells us in his paper that life is too short to attempt a complete mathematical solution of the problems involved. Yet this is precisely the task which has been accomplished by Mr. Barth. I have personally seen the patient research and hard labor of months which Mr. Barth has put into this work, purely from an unselfish devotion to the interests of our profession, and I am glad to bring this fact to the attention of the Society. It is such work as this that will give our Society high standing throughout the world.

7 As engineers, mathematics (elementary mathematics, to be sure) is one of our daily implements, so that we are qualified to appreciate the work of the pure scientist or mathematician who devotes his life either to advances made in the field of pure mathematics,

or in the application of mathematics to what may be called the field of pure science. The work of these men, while invaluable to the world in the long run, is but remotely useful to engineers; the peculiar mathematical ability displayed by Mr. Barth, however, should appeal to us as engineers far more even than the work of those engaged in pure science. Mr. Barth has displayed that analytical ability, rare with mathematicians, which has enabled him to simplify mathematical formulae so complicated as to be unsolvable, and to make them immediately practical and useful without materially deviating from their value.

8 He thus puts into our hands for daily use a new and valuable piece of knowledge, or implement, but unlike so many of our best theorists and investigators, he does not stop with developing his useful formulae. He has further embodied this knowledge in a slide-rule, so simple that by its use anyone, whether familiar with mathematics or not, can solve practically all belting problems at a glance. I hope that either Mr. Barth or someone else will arrange to have this slide-rule made available to engineers at large, at a reasonable price, and accompanied by practical directions for its use. Such implements are invaluable aids in the everyday work of the engineer, and should be in every drafting-room in the country.

9 The experiments of Messrs. Briggs and Towne and those of Messrs. Bancroft and Lewis will remain for many years as classic monuments in the development of our scientific knowledge of belting laws; but Mr. Barth's remarkable analysis of the work of former experimenters, supplemented by his accurate though less voluminous experiments on the elastic properties of belting and on the rate and extent of the fall in tension of belts, has rendered his conclusions as to economical speeds and the proper sizes of belts more reliable than those of any previous writer. His final recommendations should be accepted, therefore, rather than those in the papers of Messrs. Towne, Lewis, or the writer.

10 There should, in the writer's judgment, be added to Mr. Barth's paper a clear numerical statement giving the exact tension per inch of width to which belts of average thickness, both double and single, should be retightened each time they require tightening, and this statement should be given a prominent place in the paper, so that it can readily be found.

11 It may be of interest to know how the figure of $2.25, quoted earlier in the paper as the cost per belt per year, was found.

12 In the new machine shop of the Midvale Steel Company,

beginning in the year 1884, the writer experimented[1] with all of the belts in the shop, in practical use; and upon the comparative values of the four leading types of leather belting then in common use. This experiment lasted nine years with belting running night and day (equivalent to eighteen years running ten hours per day). Exact records were kept of all items affecting the life and economical use of belting, and at the end of the experiment, among other items, it was found that the average belt cost (under the ordinary belt rules then in use, as, for example, those used on the cone pulleys of the various machines; and on the ten hour basis) $3.34 per belt per year for the first cost plus all labor and materials used in maintenance and repairs. These are double belts, averaging 29 ft. long by 3.8 in. wide.

13 These belts were run under too high tension for economy, however. They lasted on an average 14 years (ten hours per day). The remaining belts in the shop, which proved more economical, lasted on an average not far from 28 years (ten hours per day), and cost per year per belt less than $2.50 for first cost and maintenance, etc. And this although they were materially larger than the cone belts, averaging 50 ft. long by 4.84 in. wide. The machines in this shop averaged much larger than in the average shop, and an investigation has led me to the conclusion that in the average shop the average belt would be about equal to a 3-in. double belt, 20 ft. long. The first cost plus the maintenance of this belt would not be greater than $2.25 per belt per year.

14 I hope that Mr. Barth will add to the body of his paper before it is reprinted in the Transactions one or two paragraphs emphasizing the necessity for systematic care of belting wherever it is used, by a man properly taught this work. The care of belting should be entirely taken out of the hands of the men who are running the various belt-driven machines, and belts should be systematically retightened at regular intervals, with belt-clamps fitted with spring-balances, each belt having the tightening strain carefully figured in advance. Belting should also be cleaned at regular intervals, and should be softened with the small amount of belt-dressing which is needed to keep it in perfect condition. A laborer can be quickly trained to tighten and care for all the belts in the shop during the

[1] These experiments are described in a paper entitled Notes on Belting, presented before the Society December 1893, and forming part of Volume 15 of the Transactions.

noon hours and on Saturday afternoons and at other times when the shop is not running.

15 Two elements of great importance in Mr. Barth's paper seem to me almost certain to be lost, even to those especially interested in the subject of belting, buried as they now are in the unpublished supplement. These should be taken out of this supplement and printed in the appendix when the paper finally appears in the Transactions of the Society. These items are, The Influence of Pulley Diameters on the Sum of the Tensions of the Belt, and a *condensation* of the discussion of the formula, Ratio of Effective Tensions, l^{fa}. Not only has this discussion a great theoretical interest, but the conclusions have a distinct practical value.

Mr. Charles Robbins. As Mr. Barth has said so much on the question on belting, and my purpose towards the elimination of the belt, I will discuss the paper from that point of view.

2 Mr. Barth's data will be of great service in the future to certain classes of industries using the belt to a great extent; more particularly to textile mills, where the belt has been in use for years, and the proposition is essentially that of constant and uniform speed.

3 When we took up the question of applying motors to that class of work we were informed that the principal objection was too great variation of speed. Their stated requirement seemed to be an electric drive which would give a speed as close as the mill engineers seemed to think they had, a problem that we took up with some hesitation, but in applying to spinning frames the alternating-current motors, which, as you know, are constant-speed machines and run at a very uniform speed, we discovered that the productive capacity of the frames was very largely increased.

4 This led us to make some tests as to the loss of speeds, or slip of belts, and their lack of uniform operation. The net result in using the induction motor instead of the belt is an increased production of at least seven per cent, and in some instances even ten per cent. Probably some of this increase was largely due to the fact that the belting systems tested were not designed in accord with Mr. Barth's system; but I do not believe that a system of belts will ever approach the uniform and constant speed of an induction motor. The fact remains that with the average system of belts the motor drive, on account of its uniform speed, increases the production of almost any class of machinery.

5 The question of efficiency may be classified as (1) the primary

efficiency from the engine shaft to the shaft of the driven machine; (2) the economies which result from the use of the electric motor drive. These secondary economies, which are undoubtedly the most important, will vary with the class of industry to which the electric motor is applied. It is greatest in those industries where the load time factor of the installation is lowest and where the inherent characteristics of the electric motor are of greatest value. These characteristics are as follows:

a Ability to adjust the speed according to the demands of the work.

b Absolute certainty of a uniform and constant speed.

6 While these two characteristics may seem to be opposed, they are important factors in the increase of production of different types of machines. As widely separate examples: for a machine tool the readiness with which the speed of a motor may be varied to the right quantity for the work required contributes to its increase of production; on the other hand textile mill service requires an absolutely constant and uniform speed, which is obtained from the induction motor.

7 In determining the value of an electric motor drive the essential point is always the secondary, or accruing economies from its use, rather than the primary economy, although when the primary is added to the secondary the net result will be extremely satisfactory.

Mr. Geo. N. Van Derhoef. This paper develops in a clear way principles that we have heretofore been forced to regard as intangible enigmas, and will no doubt live as one of the engineering classics of the Society.

2 The property of leather belts of continually stretching under service conditions, belongs also to other forms of transmitting bands, and is possibly inherent in any form of transmitting band possessing a fibrous structure. This means that maximum and minimum limits of initial tension must be used, or devices employed to take care of the increasing length, in which case the belt may always be operated under minimum tension, lighter weight pulleys and shafting may be employed, and the load on the bearings minimized.

3 While there seem to be very few recorded tests on the amount of energy consumed in the rapid bending and unbending of belts, it seems to be a well-defined belief among engineers that the energy lost through this cause is less than is commonly supposed. I am inclined to agree with this, and also believe that the loss due to reverse bends in belts, either in energy consumed or in destructive action on the belt, is probably smaller in amount than is usually supposed, provided these bends have a relatively large radius.

4 The author's plan of proportioning belts so that the slack will be taken up at approximately regular intervals of time, regardless of speed or power transmitted, is excellent from a theoretical point of view. He is obliged, however, to divide belts into two classes —machine belts and countershaft belts, under different initial tensions, and therefore with different periods between adjustments. I think it will be absolutely necessary to provide more classes. In some cases first cost is of greater importance, and in other cases the expense or inconvenience of taking up belts is the main consideration. With a large belt, running night and day, the stopping of the drive to take up the belt is a serious matter. In the case of many drives, however, this is a matter of small moment.

5 I have had considerable experience with large quarter-twist belts, running from 12 to 20 in. in width, for connecting horizontal and vertical shafts, and have seen results that appear incredible in view of much of the theoretical data published on belting. These belts were under high unit-tension, and always subjected to reverse bending over deflecting idlers. Probably one reason for the success of belts of this kind is the automatic regulation, within limits, of the slack-side tension, due to the belt working up and down across the face of the pulley on the vertical shaft. As far as I have observed, belt drives of this kind, when properly designed and erected, have been as satisfactory as horizontal belts with about the same distance between centers.

6 Possibly the larger unit-stresses frequently used necessitate a slight actual slipping of the belt on the pulleys, with some corresponding increase in the coefficient of friction. This should not necessarily be regarded as poor practice, but simply as a factor to be weighed against savings in first cost, friction losses, etc. There seems to be no fundamental objection to slipping within certain limits, provided such slip is a constant quantity. All belts are continually sliding, to some extent, on the surface of the pulleys, due to the theoretical creep caused by the elasticity of the belt. A little more would not necessarily be serious. The surface of a well finished leather belt is such that sliding on a polished iron pulley will not cause much harm provided the heat generated by the slip is dissipated with sufficient rapidity to prevent the temperature of the belt surface from rising too high. This, of course, involves a loss of energy, as do very large belts under low tensions, and the crowning of pulleys. The writer desires to emphasize that due consideration should be given to all the factors involved.

7 Spring belt-clamps should be used wherever practicable, and ought not to be very expensive if manufactured in reasonable quantities. In the majority of cases, however, we shall have to be satisfied with figuring belts properly, and leave the actual initial tension to fate.

8 The idea that the maximum working-stress of a belt should not be determined by its ultimate strength is, I believe, correct. This becomes more apparent in studying transmission ropes. It is a well-known fact that the maximum unit-stress for a manila transmission rope should be of such amount that the side-pressure between the lubricated fibers of the rope will not cause abrasion when the ropes bend over the sheaves, and the fibers slide on one another. Probably some such internal action takes place in the case of leather belts. In transmission ropes the ultimate strength bears a greater ratio to the proper maximum working stress than is the case with leather belts. Manila rope is therefore a very safe transmitting band.

9 The constant lengthening of belts in service has its counterpart in ropes. Where a rope is simply carried around two sheaves, as in the separate rope system, the general equation of the rope is without question similar to that which the author has shown to be true of leather belts.

10 The continuous system of rope transmission, with its automatic tension carriage, has the slack-side tension maintained at a minimum. This is one of the fundamental reasons why the continuous system can transmit the same amount of power at the same rope speed and with the same rope life, with less rope than is possible with the separate wrap system. A few years ago the continuous system was looked upon by most engineers with considerable scepticism; its enormous development in the last quarter of a century is due simply to its basis on absolutely sound mathematical principles.

Mr. Walter C. Allen. My contribution to the discussion will relate to the practical results obtained from the installation of an improved method of caring for belting, rather than to the technical phases of the question. In this connection a brief description of the working out of the improved system in the works of the Yale & Towne Mfg. Co. may prove interesting.

2 The problem of transmitting large amounts of power by means of belting is not a serious one with us, as our power is for the most part transmitted electrically; each room is provided with one or more motors, and the power is distributed from them through line

and countershafts to the machines. The great majority of our belts are small, and many of them run at high speeds. Altogether we have about 4800 belts, so that their proper maintenance is an important and somewhat difficult problem.

3 Early in 1905, at Mr. Barth's suggestion we undertook an investigation of our belting and the methods employed in its upkeep, as a result of which we decided to adopt a system of caring for belting recommended by Messrs. Taylor and Barth. For the sake of brevity I have divided my notes into comparative statements, of the conditions before and after the adoption of the new method as affecting each element of this important subject. It may seem that the conditions existing before the installation of the new plan were distinctly bad, but I venture to say that they were as good as those in many manufacturing establishments at the present time, if not better. The improved conditions, however, are so infinitely superior to the old that by comparison the latter appear extremely antiquated and crude.

4 *Tensions.* Under the old plan we had no means of knowing with any accuracy the tension of a belt. It was left to the individual judgment and experience of those doing the repairing, so that inevitably the tensions of the belts varied in proportion to the variation of judgment of the repair men.

5 The first step in the reorganization was the building of a belt bench and the provision of tension scales such as are shown in Fig. 6. These are used now altogether for the determination of tensions.

6 *Records.* Under the old regime we had no records whatever of our belts.

7 Under the new plan we have a record of each belt showing its location: its type, i. e., whether open or crossed, countershaft or machine belt; kind of leather; thickness, width and length. These records also show for each belt the dates of inspection.

8 *Organization.* Under the old plan our millwrights cared for the heavy belts, but the repairing was done only when the belt gave way, or stretched so that it failed to transmit the necessary power. The small machine belts were cared for by the individual machine operators, many of whom knew absolutely nothing about belting, and in some cases our investigations showed that ignorant operators had attempted to tighten a belt by cutting out a piece, and, finding that they had cut out so much that the belt would not go over the pulleys, were then compelled to cut out still more and set in a piece in order to make the belt long enough to do the work. In these

cases also the belts were not repaired until they actually gave out through breakage or failed to give the necessary pull.

9 Under the new plan a gang of four men do absolutely nothing else but inspect belting and attend to the repairs and retightening. A belt room has been provided in which is an annunciator, and a series of push buttons are arranged at the telephone central, so that in case of an accident to a belt the foreman or gang boss can call the belt man easily. In a plant as large as ours the annunciator results in a great saving of time.

10 A tickler system was installed by means of which the belt gang are notified regarding the belts to be inspected each day. After the inspections are made these tickler cards are returned to the office where the proper records are made and the ticklers put back for the next inspection.

11 These belt men take their lunch hour from 11 to 12 o'clock, working during the noon hour, and are thereby enabled to repair many belts which could not be repaired when the works are running, without loss of time to other employees.

12 *Fastening.* Under the old plan there was no fixed rule regarding the fastening, rawhide lacing and belt hooks being used indiscriminately. Under the present plan Jackson wire lacing, put into the belts by means of a machine, is universally used. For continuous belts, under the old plan we used a kind of glue which took from three to ten hours to set satisfactorily. Under the present plan we are using a special glue which will set hard in thirty minutes. This also results in a saving of time in the case of an accident to continuous belts.

13 *Belt Dressing.* Under the old plan comparatively little belt-dressing was used, but in many cases rosin was used through ignorance of the fact that it causes the belting to deteriorate rapidly. We now use entirely Plomo belt-dressing, which is extremely useful and tends to prolong rather than to shorten the life of the belt.

14 *Reclamation of Oily Belts.* Under the old plan no reclamation was attempted, but at the present time we reclaim a considerable amount of belting each year. Belting damaged on the edges is cut down and used for narrower belts, short pieces are scarfed and glued together and the oil is taken out of oily belting and the belts used over again.

15 *Kind of Belting.* Several kinds of belting were used under the old plan, but we have gradually standardized our belting until at the present time practically nothing but a high-grade of oak-tanned belting is used.

16 *Cost of Up-Keep.* Of course there was no method of determining the cost of maintenance under the old plan. Our records show that during the year 1906 the labor-cost of maintaining our belting system was 96 cents per belt. During 1907 it was 73 cents and during 1908, 45 cents. This decrease has of course been due to the increased efficiency of the men doing the work and to the fact that experience has indicated where inspection periods could be lengthened out, and also to the fact that the belting is now in such condition that expensive break downs seldom occur.

17 The foregoing statements describe briefly the various features of the old and the new plans: a summary of the advantages of the new plan follows:

a Decreased cost of belting. The cost for the year 1907 was only about 60 per cent of that for 1906, despite the fact that we installed more new machinery in 1907 than in 1906.

b Increased efficiency of machines, due to the fact that the tensions are maintained much more uniformly than formerly.

c Continuous production by both men and machines, due to decreased interference due to belt-breakdowns.

d Uniform type of belt lacing, decreasing danger to employees.

e Decreased cost of maintenance.

f Under the present plan the cost of maintenance appears as a separate item where it can be watched and compared with that of previous periods to determine the relative economies, while under the old plan the figures were combined with a mass of others so as to make it impossible to determine how much it had cost.

CONCLUSION

18 When we first commenced to install the new system we had all sorts of trouble as is generally the case with any new thing. The plan was opposed by foremen, gang bosses and workmen, each of whom had an idea that the new tensions were entirely wrong, and that the machines would never do the work properly, unless they could adjust the belting according to their individual ideas. One of the best evidences of the value of the present plan is that this antagonism has entirely disappeared, and what was at first con-

sidered by many an interference and a hindrance is now accepted as a help and is believed to be entirely satisfactory by those competent to hold an opinion.

Mr. Taylor. The original experiments at the Midvale Steel Works were started in 1884; 17 years later, when all the machinery in that shop was taken out, one of the belts, which was of the type of those run under proper rules, that is, approximately the low tension suggested by Mr. Barth, had run all that time night and day under heavy tension. During this time it had required tightening only nine times, and at the end of the equivalent of 34 years of ten-hour service that belt came off its pulleys and was immediately put to work on another machine, in good condition. This instance of the life of a belt properly taken care of and properly tightened will be a surprise to the man accustomed to see a belt go out of use in from two to five years. This statement has just been determined.

Mr. Dwight V. Merrick.[1] As I am interested in chain drives, I will draw attention to some experiments made by Hans Renold, Ltd., of Manchester, England, and embodied in a pamphlet issued May 1908, comparing the relative efficiency of chain and belt drives on automatic machines. Mr. Renold claims that with the chain drive the output was increased 20 per cent, fewer drills and parting tools were used, and a better finish was obtained on the work. He says: "The tool did its work *unflinchingly* at every part of the revolution of the spindle—no more and no less." He further states that the wear and tear on the spindle and countershaft bearing was considerably reduced. These statements were so striking that the Link-Belt Company, with which I am associated, decided to make further tests. In one of these which I was detailed to make I maintained a constant feed and speed and used the same tools with each drive, and in all cases the tool was used until it became necessary to re-grind, the object being to cut off as many pieces or drill as many holes as possible before this condition was reached. The tool when chain-driven did considerably more work than when belt-driven. I quote from my report as follows:

2 These tests were made on a 3 in. by 36 in. Jones and Lamson turret lathe, with "blue chip steel" cutting-off tool $\frac{3}{16}$ in. wide, cutting off cold rolled shafting $2\frac{1}{2}$ in. diameter, feed 0.012 in. per revolution.

[1] Dwight V. Merrick, Link-Belt Mfg. Co., Nicetown, Philadelphia, Pa.

TABLE 1 RESULTS OF EXPERIMENTS ON A 3 IN. BY 36 IN. JONES & LAMSON TURRET LATHE 0.012 IN. FEED PER R. P. M.

Mark on Tool	Kind of Drive	Pieces No.	Metal Cut by Tool Inches	Cutting Speed Ft. per Minute	Condition of Tool	Time Minutes	R.P.M. of Spindle
2	Belt	6½	8.125	94	Ruined	5.91	143
	Chain	16	20.	94	Ruined	14.70	143
	Belt	9	11.25	94	Ruined	7.15	143
5	Chain	7⅞	9.843	128	Ruined	4.81	196
	Belt	4⅞	6.093	134	Ruined	2.72	203
4	Belt	1	1.25	134	Good	0.51	203
	Belt	¼	0.312	151	Ruined	0.12	231
	Chain	1	1.25	126	Good	0.54	193
	Chain	¾	0.937	151	Ruined	0.39	231
1	Belt	1	1.25	129	Good	0.53	197
	Belt	½	0.625	146	Ruined	0.15	223
3	Chain	1	1.25	129	Good	0.53	197
	Chain	1	1.25	149	Fair	0.44	228
	Chain	⅜	0.468	195	Ruined	0.15	299

NOTE: A higher cutting speed was obtained by the chain drive.

TABLE 2 RESULTS OF EXPERIMENTS ON A DRILL PRESS WITH NEW ⅞ IN. DIAMETER CARBON STEEL DRILLS, 0.018 IN. FEED PER REVOLUTION, IN A SOFT CAST-IRON BLOCK, 3 IN. THICK

Mark on Drill	Kind of Drive	Holes Drilled Number	Metal Cut by Drill Inches	Cutting Speed R.P.M.	Condition of Drill after Drilling Holes	Time Minutes	R.P.M. of Spindle
1	Belt	31	93	62.2	Started to ruin	18.91	273
1	Chain	57	171	60.5	Corner rounded, needed grinding, starting to ruin	35.91	264
2	Chain	37	111	62.2	Starting to ruin	22.57	273
2	Belt	20	60	62.2	Starting to ruin	12.20	273

NOTE: A great many more holes were drilled by the chain drive.

TABLE 3 RESULTS OF EXPERIMENTS ON THE SAME DRILL PRESS AS IN TABLE 2 WITH NEW $\frac{23}{32}$ IN. DIAMETER CARBON STEEL DRILLS, 0.018 FEED PER REVOLUTION, IN A VERY HARD CAST-IRON BLOCK, 3 IN. THICK

Mark on Drill	Kind of Drive	Holes Drilled Number	Metal Cut by Drill Inches	Cutting Speed R.P.M.	Condition of Drill after Drilling Holes	Time Minutes	R.P.M. of Spindle
3	Chain	17	51	28.0	Starting to ruin	19.84	148.8
3	Belt	14	42	28.4		15.40	151.4
4	Chain	17	49½	28.0	Started to run on 17th hole 1½ in. deep	18.48	148.8
4	Belt	13	39	28.2	Started to ruin	14.44	150.0

NOTE: More holes were drilled by the chain drive, but the percentage of gain was not anywhere near as great as in Table 2.

3 Care was taken in forging, treating and grinding the several tools used, to insure uniformity in their cutting qualities; but to obviate the possibility of the results being affected by the cutting qualities of the different tools, each tool was used with both drives.

4 One of the tools cut off 16 pieces when chain-driven before it became necessary to re-grind, and only 9 pieces when belt-driven. The cutting speed in both cases was 94 ft. per minute, feed 0.012 in. per revolution, and another tool cut off 8 pieces when chain-driven against 5 when belt-driven. In this latter case the cutting speed was 130 ft. per minute, feed 0.012 in. for chain and belt.

5 As the cutting periods in the above test were so short, two more series of tests were made with longer continuous periods. These tests were made on a drill press with new $\frac{7}{8}$ in. carbon steel drills in a soft cast-iron block, 3 in. thick. The same drill was used on both drives, and was carefully and uniformly ground for each test.

6 One of the drills when belt-driven drilled 31 holes before it became necessary to re-grind, but when chain-driven the same drill drilled 57 holes; the cutting speed in both cases was 62 ft. per minute, feed 0.018 in., and another drill at the same speed and feed drilled 37 holes when chain-driven, against 20 when belt-driven.

7 The other series of drill tests was made on the same drill press, with $\frac{23}{32}$ in. carbon steel drills on a very hard cast-iron block, 3 in. thick. One of the drills when chain-driven drilled 17 holes before it became necessary to re-grind, against 14 holes when belt-

driven; the cutting speed in both cases was 28 ft. per minute, feed 0.018 in. per revolution, and another drill did 17 holes, chain-driven, against 13 belt-driven, same feed and speed as above.

8 The results were so gratifying that further tests are being made on four similar automatic machines, at our plant in Indianapolis, two fitted with belt drives and two with chain drives. The same feeds and speeds will be maintained with each drive throughout the series of tests, but a variety of tests will be made to establish the maximum efficiency of both belt and chain drives, to the best of our ability. The results will all be tabulated and published in a pamphlet in the near future.

9 The accompanying tables contain the tabulated results of my experiments.

Mr. F. A. Waldron. After listening to this paper, one naturally asks the question, What is its commercial value? Mr. Allen has answered this very well, but I will give a little of my own experience with the system.

2 At the plant of the Yale & Towne Company, most of the responsibility for the condition of belts, prior to the author's going there, was placed with me and I am willing to take any criticisms. I became an ardent advocate of Mr. Barth's work on belts, however, particularly because of the practical results obtained.

3 After leaving the Yale & Towne Company, I had occasion to purchase a Barth bench and spring-balance and apply the elements of the system without spending a large amount in replacing countershafts. I established the system of varying tensions on different machines. A light countershaft would not stand as heavy tension on the belt as the author originally prescribed. Tensions on belting, lengths, taking up, etc., were recorded. A record of complaints received in the millwright department for a specified number of countershafts and machine belts had been kept, and for ten days or two weeks before installation something like 150 complaints came in. After complete installation of the Barth bench and scales and the Barth system, the complaints dropped to 80 for two weeks, and six weeks later to 35, showing the commercial results of systematic care of belts.

4 Belts as low as 1½ in. wide, and some heavy double belts three to four inches wide, were the limits on size.

5 This system was installed almost at the cost of my reputation, and on leaving that concern I supposed that the belt bench and

bench-scales would be relegated to the scrap heap. Having an opportunity to put in a belt-bench and scales elsewhere, however, I wrote the firm asking if they did not want to sell the bench and scale and they said "no."

Mr. A. A. Cary. I was much interested in Mr. Allen's remarks concerning the employment of Mr. Barth's system and formulae for the selection and proper application of belts to drive the numerous machines at the Yale & Towne plant, but explanation of one essential point is needed to show how this can be practically accomplished.

2 As I understand, one important factor required in the formula used to determine the proper initial tension to which each belt must be subjected when put in place, is the horse-power to be transmitted by that belt. It has been stated that 4000 belts are used in this plant, operating perhaps one-half that number of machines. I would like to know the method employed to determine the power requirements of each of these machines so as to obtain the required value of this factor when the formulae are used.

3 If we merely *guess* at the power required, we depart from the exact scientific method of determining information in our belt problems and recede toward the "rule of thumb" method, as a formula is no more exact than is the value of the most uncertain quantity employed in its solution. If Mr. Barth can give us any "short cut" method for determining the power required by machines to be driven by belts, he will funish information that will give his formulae a very practical value.

4 I have had considerable experience in determining the power required to operate machinery by use of the steam engine indicator, with dynamometers of several forms and through readings obtained from electrical instruments, but this work is complicated and requires considerable time and preparation. I hope that Mr. Barth can give us a simpler method, with which the value of his excellent paper will be greatly increased.

Mr. A. F. Nagle. This paper does not pretend to present any new facts, but sets forth, in mathematical formulae and diagrams, data obtained by Messrs. Lewis, Taylor and others. It also diagrams some simple arithmetical computations. As a work of mathematical study and diagrammatic representation, the paper is admirable, but as a practical aid to a busy engineer, it seems to me too complicated. The only part which holds my attention is the diagram in Fig. 3,

giving the horse power of belts at different velocities, and of two types spoken of here as countershaft and as main drive belts, but more commonly designated as "single and double thickness." The reason for this distinction is that while the stress in the net solid body of the leather is taken to be the same in each case, in "single" belts the joint is a butt joint and is laced. This cuts away more of the belt than where the belt is of double thickness, lapped and cemented, or riveted; the difference being in the character of the joint rather than in the thickness of the belt.

2 For comparison then, we can take Mr. Barth's estimate of the relative strength of these belts, as 160 to 240 or 1.0 to 1.50. Mr. Towne found these to be as 1.0 to 1.82, and in my early studies, I was inclined to adopt this ratio; later, however, I have used the ratio of 275 to 400 or 1.0 to 1.45.

3 The belt problem is very far from being one of pure mathematics. As in most engineering problems, there is about 5 per cent of scientific knowledge involved, and fully 95 per cent of good judgment based upon experience. We rarely know the exact power to be transmitted except in the case of prime movers. The arc of contact, the velocity, and the stress we are willing to put upon the leather, are all easily determined, but we cannot decide upon the coefficient of friction by formula. A new leather belt upon an iron pulley may not have a coefficient of friction of 25 per cent, while the same belt, well worn and well groomed, will give 65 per cent in a clean, dry room; put the same belt in a wet place, like a tannery, or a dusty place, like a stone-crushing plant, and we have an entirely different coefficient.

4 It seems to me that the designing engineer, even though he understands the mathematics of the belt problem, if ignorant or unappreciative of the practical conditions under which the belt works, will be liable to make a mistake. On the other hand the engineer familiar with the conditions, but ignorant of the mathematics involved, is also liable to error in his conclusions. A cautious man will endeavor to err on the safe side, feeling no doubt as our venerable ex-President Mr. John Fritz did, who when remonstrated with for making some machinery needlessly strong, replied, "If I do, nobody will ever find it out."

5 On general principles, it is of course desirable to work belts, like other members of a machine, with large coefficients of safety, but engineering, in its last analysis is a question of finance and we must "hew as close to the line" as possible. Mr. Towne found the ultimate strength of laced belts to be 200 lb. per inch width ($\frac{3}{16}$ in.) thick,

and used $\frac{1}{3}$ of this, or $66\frac{2}{3}$ lb. as a safe working stress. Mr. Towne also found a coefficient of friction of 42 per cent to be safe. The general practice of the day has been quite close to these factors, but if I understand his diagrams correctly, Mr. Barth has departed far from them.

6 In 1881 I read before the Society a paper giving for the first time, I believe, a belt formula which took cognizance of the effect of centrifugal force. The data used therein were based principally upon Mr. Towne's experiments. The results obtained were well within the safe limits of previous practice for low speeds, but at high speeds my formula showed the deviation. Common formulas gave results (see Kent, Mech. Eng. Pocket Book, p. 879) as follows:

For single belt 1 in. wide, 600 ft. per minute (1) 1.09 h.p. (2) 0.65 h.p. (3) 0.60 h.p. (4) 0.82 h.p. Nagle 0.73 h.p. Barth gives only 0.40 h.p.

For double belt, common formula 1.17 h.p. Nagle 1.24 h.p. Barth 0.68 h.p.

7 For the purpose of giving a clear conception of Mr. Barth's deviation from the others, I repeat my formula here:

$$h.p. = \frac{C.\,V.\,t\,w\,(S - 0.012\,V^2)}{550}$$

C is a constant expressing the adhesion of the belt upon the pulley under a unit of stress of belt. Its value is expressed by the equation $C = 1 - 10^{-0.00758\,f\,a}$ where a is the arc of contact and f the coefficient of friction. The other quantities are as follows:

V = velocity in feet per second.

S = Stress upon leather per square inch, which I have taken at 275 lb. for laced and 400 lb. for riveted belts.

t and w are the thickness and width respectively in inches.

$500\,f\,t\,w$ = horse power per sec.

8 To illustrate the solving of this equation, let $a = 180$ deg. and $f = 0.40$, then

$$180 \times 0.40 \times 0.00758 = 0.54576$$
$$01^{-0.54576} = \log 10 \times 0.54576 = 1 \times 0.54576$$

0.54576 is a logarithm of which 3.513 is the number. This being a minus coefficient, we must take its reciprocal or 0.284; substracting

this from 1, we get 0.716. The result could have been obtained by subtracting the log 0.54576 from 1, giving 1.45424, and this gives 0.2846 as its number direct.

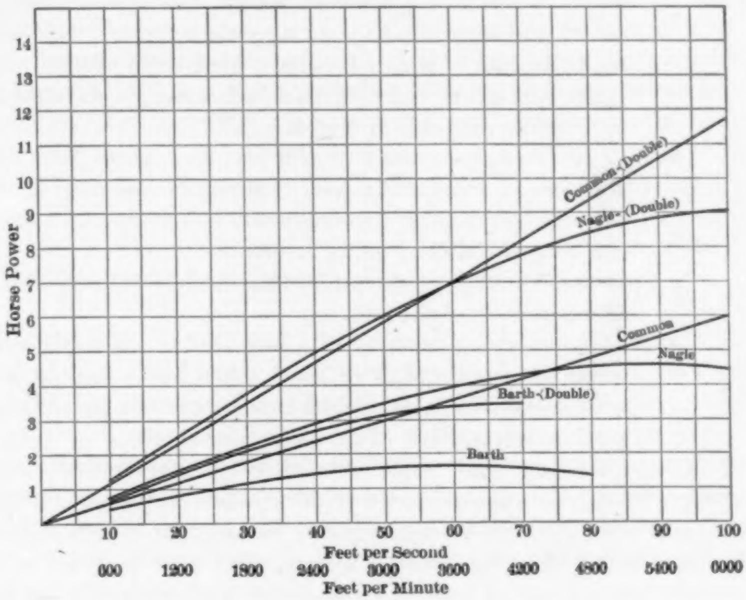


FIG. 1 COMPARISON OF DIFFERENT BELT FORMULAS, BASED UPON BELTS 1 IN. WIDE AND $\frac{7}{32}$ IN. THICK FOR SINGLE AND $\frac{1}{4}$ IN. THICK FOR DOUBLE BELTS

9 In Kent's Mechanical Engineering Pocket Book, p. 878, tables are given based on this formula, which facilitate its use. I wish to call attention to the wide divergence of Mr. Barth's conclusions from those commonly used as well as from my own, as plotted in Fig. 1 herewith. I have reduced his figures to the same thickness as mine, namely $\frac{7}{32}$ in. for single and $\frac{1}{4}$ for double.

10 This work has been done somewhat hastily and I hope the author will check it at least so far as relates so the interpretation of his diagram. If my work is correct, I am puzzled to understand why his tables of belt horse power differ so much from mine.

PROF. WM. W. BIRD. I feel very much pleased and highly complimented to see the results of Mr. Barth's mathematical analysis of

my experiments on belt creep. On a few points, however, I am still in doubt in regard to his general conclusion. I believe:

a That the elasticity of a belt varies with the velocity and that at very slow speeds the sum of the tensions would remain constant, while at high speeds, if it were not for the centrifugal force, that the sum would increase practically with the load. If this is true, a belt will improve with higher speeds and will not reach a maximum at 4000 ft. per minute as shown in Fig. 3.

b That in determining the size of a belt for a given load, the diameter of the smaller pulley should be considered. A belt will do relatively less on a small pulley than on a large one, other conditions being the same.

c That the crowning of the pulleys should be considered as it affects the life of the belt.

d That the carrying capacity of a belt should not be given in terms of square inches of cross section, as a double belt with one square inch of cross section will not transmit as much as a single belt of the same cross section.

2 I have recently made some tests on compound or rider belts and have been somewhat surprised at the relative movements of the main and rider belts with various pulley ratios, from which I have concluded that if these belts were glued together, as they would be in a double belt, numerous internal stresses and strains must be set up when the belt passes over a pulley, especially over a small one.

3 The crown is a very serious matter on a small pulley, as the following figures will show. Take a 4 in. pulley with a crown of 0.2 in. in the diameter, if the belt wraps 180 deg., the length in the middle of the belt will be 0.31 in. greater than on the sides; this means a stretch of 0.05 in. per inch or 1000 lb. stress on middle fiber, taking modulus of elasticity as 20,000 lb. The belt must slip or be ruined, for this stress does not include load or initial tension and is in itself enough to stretch the belt beyond the elastic limit. The slipping necessary to adjust this stress must influence the friction and slipping of the belt as a whole.

4 I would like to have Mr. Barth answer a question which I have been asked a great many times,—why does the sum of the tensions in a belt increase with the load? I would also like to have him calculate with his slide-rule the size of a belt for the following conditions: 20.h.p. motor, 6 in. pulley, 1200 r.p.m., to drive a shaft 12 ft. away at 200. Would the same belt last as long if the drive were reversed,

that is, a shaft running at 200 r.p.m. driving a generator with 6 in. pulley at 1200? I would like also to ask Mr. Barth or any engineer present whether he would use the same size belt with the 6 in. pulley as a driver as with it as a driven, and with the same size of belt; and whether in this case it would last longer, other conditions being equal.

5 Anyone who has undertaken an investigation of the belt problem knows that it is almost impossible to keep conditions constant—humidity, oil in the belt, surface of pulley, etc., seem to change without notice and complicate the work.

6 I wish to congratulate Mr. Barth on his efforts to advance the theory of the transmission of power by leather belting, and to agree with Mr. Lewis in the conclusion of his paper presented in 1886, "That there is still need of more light on the subject."

Prof. C. H. Benjamin. I have been asked to contribute to the discussion of Mr. Barth's paper; technically, I am afraid I can not criticise it or add to it, for it leaves but little more to be said. Sentimentally, I can not but regret the gradual disappearance of our *terra incognita*, both geographical and mechanical. Time was when large areas on the map bore the encouraging legend "Unexplored Wilderness" or "Great American Desert" and left room for the free play of the imagination. Today you miss those fascinating areas and are tied down to realities.

2 Not many years ago, the grinding of a lathe tool was an interesting experiment, attended with much uncertainty, and the matter of feeds and speeds offered an alluring field for investigation. Mr. Taylor has spoiled all that for us and now our imagination is worked by slide-rule.

3 Time was when the possibilities of belting were vague in outline and when coefficient of friction, slack tension and belt creep were rather shadowy phantoms. It was pleasant then to speculate on what the belt would do and how long it would do it and the man with the longest memory had the advantage. But now, Mr. Lewis, Mr. Bird and Mr. Barth have taken all the romance out of it and another illusion succumbs to the deadly aim of the slide-rule.

4 Perhaps I take a malicious pleasure in noting that one or more factors of the problem are still out of harness and a trifle intangible. Our old friend, the coefficient of friction, is in hiding under the belt sporting with those other elusive fairies, modulus of elasticity and belt-creep. After all, what does it matter? Aside from the interesting

theoretical questions involved, what we need to know is, first, how wide a belt to use at a certain speed to transmit a certain power,—Mr. Taylor has answered this question. Second, how tight to lace or cement that belt that it may do the work for a reasonable time without relacing,—Mr. Barth has told us that.

5 I began experimenting on belts 25 years ago and have been at it more or less since. With a fixed pulley and a slipping belt, I found no difficulty in proving $\phi = 0.42$ after Rankine, but when I built a belt machine and tested belts under running conditions, ϕ lost all its constancy and might as well have been called x. Working backwards from the measured tension and using the old formula, I found ϕ to vary with the load, the speed, the kind of pulley, the age of the belt, the weather and the dominant political party—in fine, to be so mysterious and intangible a quantity as to be useless for practical purposes.

6 The sum of the tensions also varied in a manner that did not admit of rational explanation. And right here let me say that the reasons for Mr. Barth's assumption of constancy for $(t_1 + \frac{1}{2} t_2)$ are hardly clear to me. Why call that constant which is not constant? Why call anything constant except as it is shown to be so by measurement? This is not said in criticism but for the sake of information.

7 There is one aspect of the paper that deserves special attention and that is the recognition of the fact that a belt is an elastic connector with a variable length and variable tensions. Most writers on the subject have treated belting as if it were a non-extensible element which could be exactly represented on paper and whose behavior was capable of exact mathematical analysis. A belt in action is almost like a thing alive, squirming, lengthening, shortening, its tension changing back and forth with a variable modulus of elasticity and a lag in its changes due to its contact with the pulley and the short time intervals. A belt must be tested to be appreciated and theory must wait upon experiment.

8 I fully appreciate the value of Mr. Barth's analysis and can see that his methods will result in marked economies in establishments where many large belts are used and where conditions are pre-determined. In the smaller shop, where conditions vary, and in isolated cases with differing sorts of pulleys, differing kinds of belt, new and old, I feel that each case will have to be settled on its own merits. Until more experiments are recorded, the average machine-designer or millwright will have to be guided largely by his own judgment and experience in determining the width and tension of each belt. Let us have more experiments.

Mr. H. K. Hathaway.[1] To the scientist and machine-tool designer the value of Mr. Barth's paper will unquestionably be immediately apparent, but the writer feels that the paper does not represent with sufficient clearness features of the problem that are of inestimable value to the engineer concerned with running a shop. Assuming that the designer takes care of the sizes of belts required, and the speed at which they should be run, in accordance with the conclusions of such eminent authorities as Mr. Taylor, Mr. Barth, and Mr. Lewis a great deal is lost unless the shop-man properly cares for the maintenance of such belts. As Mr. Barth has pointed out, the care and maintenance of belting in the great majority of shops is done by rule of thumb, and left entirely to the judgment of the shop millwright or the workman operating the machine.

2 The efficiency of a belt-driven machine largely depends upon the tension of the belts being properly maintained at a point above the minimum initial tension at which they will transmit the power required. This point Mr. Barth has only slightly touched on, whereas the writer feels that this subject should have occupied a section fully as large as the body of the paper presented.

3 If a machine stands idle during working hours while the belt is being repaired or tightened it produces nothing during that time, and there is a distinct loss to the manufacturer. If a machine stands idle for one-half hour out of ten hours working time there is a loss of 5 per cent in the output of that machine and if in a shop having 100 machines, 10 machines out of the 100 lose one-half hour each day on account of repairs to belts it amounts to a loss of 0.5 per cent on the total output of the shop. This feature, however, is probably not so bad as the loss in output due to the machine belts being run so loose that they cannot begin to take the feeds, speeds, and depths of cut for which the machines are designed and that the tools will stand.

4 The writer has had considerable experience with the system of maintenance of belting mentioned in Par. 67 of Mr. Barth's paper, and will describe it briefly.

5 Almost every foreman or superintendent, in attempting to bring up the speeds of his machines to something like what he knows to be possible, has found that such attempts usually result in the belt's slipping or breaking, or the lacing giving out, and knows that where the care of belts is left to the man on the machine, only in a very few cases can the belts be depended upon to do the maximum

[1] Mr. H. K. Hathaway, The Tabor Mfg. Co., Philadelphia, Pa.

amount of work. If, therefore, the maximum feed, speed and depth of cut are to be prescribed and used, as is done by the aid of Mr. Barth's slide-rules under the Taylor system, it is essential that belts of the best quality and of the proper proportions be used, and that they be kept in first-class condition and at the proper tension, so that they can be relied upon to give the pull required. It is also necessary that all repairing, tightening, and inspection of belts be done outside of working hours that there may be no loss of output from interruption to manufacture. In order to accomplish these objects the following system has been evolved.

6 A record is kept for each belt in the shop on the form shown as Fig. 1, on which are given all standard data for each belt in question.

7 When a new belt is to be put on, or an old belt to be inspected or tightened, the special belt fixer's bench developed by Mr. Gulowsen is used, together with the belt-tension scales referred to by Mr. Barth. With this apparatus it is possible for one man to remove, tighten and replace almost any belt in from six to eighteen minutes. In putting on a new belt, or tightening an old one, the drums or pulleys on the belt bench are set by means of a steel tape to correspond with the distance over the actual pulleys, as previously determined, and shown on the belting record as "Length over Pulleys." A roll of belting, of the proper width and thickness, is next placed in the open drum, and passed through one pair of clamps of the belt scales around the drums or pulleys and through the other pair of clamps of the belt scales. The clamps are then tightened on the belt and the belt drawn up by means of the screws until the spring balances between the two pairs of clamps record the tension required, after which the belt is cut off so that the two ends will come together, and the belt is laced on a belt-lacing machine and put on its pulleys.

8 A memorandum, which also serves as the belt fixer's order and time card, giving him all necessary instruction, is then placed in what is called the "tickler," a portfolio having a compartment for each day of the year, under the date on which the belt will probably require re-tightening, and on that day it will be removed from the tickler, together with the memoranda for any other belts requiring attention, and sent to the belt fixer for attention during the noon hour and after quitting-time.

9 These belts are then removed from their pulleys, taken to the belt bench and tested to ascertain whether they require tightening; if the tension is found to have fallen to approximately the minimum,

BELTING DEPARTMENT............ BELT SYMBOL

Location..	Length over Pulleys........................	Max. Velocity..............
Purpose..	Width..	Min. Velocity..............
Kind..	Thickness..	Max. Tension.............. { ON EACH SPRING BALANCE
Maker's Name..	Cross Section in sq. in........................	Min. Tension..............
Date Put in Use..	How Fastened..	Cost of Belt........................
Date Taken Out..	Belt Grease to be used........................	Cost of Maintenance..................
Life of Belt..	Belt Dressing to be used........................	Total Cost........................

Date Re-Tightened	Tension in Pounds Indicated by Each Spring Balance		Amount Taken Out	Date Tension Again Should be Taken	Date Cleaned and Greased	Date to be Cleaned and Greased Again	Date Dressing put on During Service	General Remarks about Work Done on Belt, Condition of Belt, etc.	Workman's Name	Man's Time Required to do Work	Cost of Work
	Before Tightening	After Tightening									

Fig. 1 Belt Record for Individual Belts

they are drawn up to the maximum tension as previously described. a piece is cut from one end, the belt is re-laced and put back in place and these facts are noted on the belt fixer's memorandum, which is then returned to the planning department, and entered on the belt record; and a new memorandum placed in the tickler under the

Out In		Order Number D L
Department Day Rate....................		Man's Time....................
Max. Tension	Min. Tension	BELT SYMBOL

Cleaned and Greased....................Grease Used....................

Dressed While in Use....................Dressing Used....................

Amount Taken Out....................Length Put In....................

Length of Splice....................Cement Used....................

Tension in Lbs. Indicated by Each Spring Balance { Before Tightening.................... After....................

Workman's Name....................Man's No..........

Entered in		
Pay Sheet	Cost Sheet	Belt Record

....

DAY WORK time note

FIG. 2 BELT FIXER'S ORDER AND TIME CARD

date on which the belt will again require attention. Notices for scraping, cleaning and greasing the belts at proper intervals are also placed in the tickler.

10 The length of time a belt will run before the tension will fall to the minimum at which it will pull all that is required, has been determined from experiments, and a belt seldom requires attention before the time set for re-tightening; when this does occur, however,

a belt-dressing which does not injure the belt, but which will enable it to pull properly until noon or the end of the day, is applied, and the memorandum is removed from the tickler and another placed under its next date for re-tightening.

11 The system described accomplishes four things of vital importance to economical production:

- *a* Freedom from interruption to production from having to repair belts during working hours, by having all belts systematically inspected and all breakdown and slippage anticipated and prevented before they occur.
- *b* Possibility of using the maximum feeds, speeds and depths of cuts at all times.
- *c* Increase in life of the belt owing to all belts being of the proper dimensions and properly laced and spliced and run at the proper tension.
- *d* Reduction of cost of maintenance to a minimum.

12 Mr. Barth's belting slide-rule is used in determining the dimensions of the belts, the maximum and minimum tensions. The writer can speak from experience of the great value of the belting slide-rule in solving the belting problems that confront the shop engineer, and while the mathematical features of Mr. Barth's paper are unquestionably interesting to many, the writer feels that, like himself, many will be glad to accept Mr. Barth's figures without question provided they can have the slide-rule.

13 It is a fact that in the average shop very few belts become unfit for use through legitimate wear, but rather through accidents or improper care. Where the care of the belts is left to the workman, the belts are usually far too loose, and when a belt slips it is less trouble for the workman to reduce his speed, feed, or depth of cut, or as a last resort to use rosin to make the belt pull. This use of rosin will ruin any belt in a very short time.

14 Very few machinists or even foremen know how to tighten or lace a belt properly, the amount to be taken out being usually guessed at, and a great deal of time is lost through the machine's standing idle while the cutting and trying is going on. The writer has seen a good machinist run a cone belt, which he had made too tight, on "cross cones," i. e., on steps not in line with each other, with the result that it twisted itself up like a corkscrew and was practically ruined.

15 Another cause of premature ruin of belts is improper lacing, the

ends not being cut square and the lacing on one side stretching more than the other, causing the belt to run crooked.

16 Cemented splices, when properly made, give the best results. Machine lacing, using a spiral wire lacing, while not so good as a cemented splice, is very satisfactory, however, and more convenient, and takes less time for putting on and taking off belts for the purpose of testing and tightening on the belt bench. A belt joined by a cemented splice must be tested and spliced in position, which is not so convenient as on the belt bench, especially in the case of overhead belts. Even where cemented splices are used the belt bench is convenient for cutting new belts, or re-tightening to a length giving the proper tension, and for repairs. Only one wire joint is used in any belt, splices being made if a section becomes damaged so that a new piece must be set in. The average belt if cared for under this system will last from six to eight years.

17 The tension on a new belt falls very rapidly, and our present practice is to tighten it after 24 hours, then in 48 hours, then in one week, then in two weeks, and so on doubling the length of intervals until it gets to three months; from this point we must ascertain by trial for each belt how much greater the intervals may be. This of course depends upon the severity of service the belt is called upon to perform as well as the quality of the belt.

Prof. L. P. Breckenridge. The American Society of Mechanical Engineers is to be congratulated upon this valuable and comprehensive contribution by Mr. Barth. He has done this work so well and presented it in a shape so usable, that I believe it will be, for many years, the standard of reference for those who are to decide upon the specific duties which belts of various widths shall be called upon to do. This paper again emphasizes the necessity for coöperation between the expert investigator and the mathematician who can analyze the results obtained. The specialized professions are becoming more and more dependent upon the help which each can give the other; engineering, in the future, will be more closely allied with the sciences of chemistry, physics, mathematics and mechanics, so that by the study of existing data principles may be established which the engineer cannot himself disclose.

Prof. Wm. S. Aldrich. The author has adopted a valuable and unique procedure in the preparation of technical papers; namely, to derive guidance for practical work from theory, and to submit that

theory to the rigorous requirements of extensive daily use before submitting it to the Society. It is needless to add that the theory which has stood that test is all the more invulnerable.

2 If appraisal is to be made of a given hypothesis or theory according to its utility, then surely Mr. Barth's theory of the transmission of power by leather belting has the highest commendation. It has worked, and that is the best test of the truth of new theories for the engineer. If machine tools are cutting metal today in the most intensive use of modern methods and driven by belting whose effective pulling power has been readily predetermined by slide-rules constructed according to Mr. Barth's theory of what leather belting ought to pull, then his deductions are reasonably secure. What are two or three of the most salient of these?

3 In the first place, the academic discussion of the constancy of the sum of the belt tensions under all loads is finally set at rest. Now that we really know what is what, by the invaluable series of experiments referred to, the wonder is that this fallacy of the constancy of the sum of the belt tensions is so persistent in academic circles.

4 It was doubt of this position that led the writer to analyze for himself the experiments on belting then available, those of Mr. Wilfred Lewis and J. S. Bancroft, undertaken for Wm. Sellers & Co., and of Professor Lanza, of the Massachusetts Institute of Technology. Both of these were recorded in papers read before the Society, and published in Vol. 7 of the Transactions. It is remarkable that these classic experiments have been before the world thus long, and yet so little studied and respected, and, as far as the writer is aware, have not been superseded by experiments in their special field with more modern apparatus. Until they are superseded, Mr. Barth's conclusions must stand, a remarkable instance of the deductive reasoning by which it would seem that engineering progress must be made.

5 On the other hand, Mr. Barth has built up, in characteristic fashion, from theoretical considerations more or less influenced by a knowledge of the phenomena of belt-transmission, combined with the physical properties of belting, certain new and helpful relations that must govern in the future. Such is his "new theorem of the relations of the tension in a belt," that "Under any variation of the effective pull of a belt, the sum of the square roots of the tensions in the two strands remains constant, as against the old fallacious supposition that the sum of these tensions remains constant." (Appendix, Par. 26). Therefore,

$$\sqrt{T_1} + \sqrt{T_2} = 2\sqrt{T_0} \quad \text{.................} \quad (1)$$

6 Now, if we can obtain a similar relation for the difference of the square roots of the tensions, then we shall have at once, by the usual formula for the product of the sum and difference of two quantities, the difference of their squares; that is, in this case, the difference of the squares of the square roots of the tensions, which is the difference of the tensions, or the pulling power sought.

7 This much needed "difference of square roots of tensions has been indicated by Mr. Barth (Appendix Par. 14), "on the strength of the experiments made by Mr. Lewis and himself, namely, that within the limits of ordinary working tensions of a belt, the difference between the lengths of a belt at different tensions is proportional to the difference between the square roots of those tensions." We thus have,

$$L_1 - L_2 = K\,(\sqrt{T_1} - \sqrt{T_2}) \quad \ldots\ldots\ldots\ldots\ldots (2)$$

in which K is a constant, dependent upon the material of the belt, and determined by experiment on the belt.

8 Combining with Equation 1, we have, as already indicated

$$T_1 - T_2 = 2\sqrt{T_0}\,(L_1 - L_2)\,\frac{1}{K} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

It seems to the writer that this might possibly be a helpful deduction, though it may be without much practical application; so that knowing the initial unit tension T_0 and the lengths of the belt under the tensions T_1 and T_2, together with the constant K, its pulling power $(T_1 - T_2)$ is known. It seems, therefore, necessary to know the difference in the lengths of the belt, due to differences in the belt tensions, that is, to the different driving powers under which it is expected to operate the belt, or in other words, to calibrate the belt-performance for this use.

9 It may be remarked, in passing, that the constant K is to be found from the experiments of Mr. Lewis, as analyzed by Mr. Barth (Appendix, Equation 3),

$$L_t = L\left(1 + \frac{\sqrt{t}}{864}\right) \quad \ldots\ldots\ldots\ldots\ldots (4)$$

in which L_t equals the length of belt under the unit tension t when its slack length is L. From this, by analogy with the above Equation 2, we have,

$$K = \frac{L}{864} \quad \ldots\ldots\ldots\ldots\ldots (5)$$

10 It will no doubt appear that the writer is still inclined to let the arc of contact and the coefficient of friction of belts take care of themselves, notwithstanding the keen discussion that has centered about the fourth conclusion in his paper, referred to by Mr. Barth; namely,

> "(4) The ratio of the tensions of a belt-transmitting power cannot be calculated with any degree of accuracy by means of the well-known belt formula:
>
> $$\frac{T_1}{T_2} = \theta^{f\theta} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$
>
> involving the arc of contact θ and the coefficient of friction f."

11 This relation is no doubt a guide and a help, indicating the way the ratios of belt tensions are most likely to be involved. But it certainly requires a radical modification to adapt it to any reliable use in predetermining the ratio of tensions for lacing up belts for given pulling power. Mr. Barth has wrought out these modifications with excellent results, judged by the adaptability of his slide rules, and the closeness of approximation to actual conditions (within the limits assigned) of the assumptions upon which they are based; namely (Par. 44), "that for the driving belt of a machine the *minimum initial tension* must be such that when the belt is doing the maximum amount of work intended, the *sum of the tensions on the tight side of the belt and one-half the tension on the slack side will equal 240 lb. per square inch of cross section for all belt speeds;* and that for a belt driving a countershaft, or any other belt inconvenient to get at for re-tightening or more readily made of liberal dimensions, this sum will equal 160 lb."

12 Here, then, is a definite acceptance of things as they are, and a straightforward assumption involving additive relations of belt tensions of leather belting, as it is made and used, and conformable to experience, rather than their ratios agreeable to theoretical formula, involving coefficient of friction and arc of contact. This latter relation (6) is as elusive as the traction-coefficient in railroad work; and engineers probably will have their own opinions about each until some genius can predetermine what coefficients of friction are to be expected in every instance, and so properly introduce the friction for dynamic conditions into a formula based entirely upon a consideration of statical relations.

THE AUTHOR. In reading the unexpectedly numerous discussions of this paper, the author is pleased to note the general appreciation of it as a contribution to the literature of its kind, but regrets the assumption by two or three of the discussors that he considers the paper final in its application of the theories developed. All that is claimed is that he has taken practical advantage of the experimental data at his disposal, and has taken the pains to do mathematical justice to them, deriving therefrom excellent results in the scientific running of machine tools whose belts have been tightened and worked according to the rules thus established.

2 While the author feels guilty, therefore, of narrowing to a considerable extent the scope within which Professor Benjamin's imagination may still run rampant, so far as the behavior of a leather belt goes, he fully agrees that further experiments are needed in order to determine the coefficient of friction under all the variable conditions under which belts are called on to drive; and yet more, in order to settle conclusively whether the coefficient of friction is a function of the velocity of slip, as he has assumed, or of the percentage of slip, as indicated by Mr. Hamerstadt's study of numerous experiments at different belt speeds, though the latter seems contrary to the mechanical principles involved in the phenomenon of slip.

3 For the special benefit of Professor Bird, the writer will even say, that while all he knows about belting could probably be reduced to a pamphlet three times the size of his paper, a good-sized volume would probably be required to hold all he does not know but would like to know about belting, and a small library would be required to record all he does not care a straw to know about the subject.

4 But while the writer agrees with Mr. Hamerstadt as to the desirability of further experiments and will look forward to these with the keenest interest, he does not see the force of his argument about the necessary overload capacity of a high-speed belt, on a motor with an overload capacity; surely we need only make the belt big enough to take care of the overload as a normal load, and be satisfied to have it unnecessarily large for the rated capacity of the motor; just as a bridge intended for a light normal load must still be made strong enough for any anticipated occasional extra load. Trouble arises only when we do not know how to design a bridge properly, or when we get an occasional extra load which we have had no reason to anticipate.

5 Though the writer had not expected to be forced to express himself on the question of belt-drives *versus* electric motor drives, he

will say, in view of Mr. Robbins' remarks, that he believes that during the past decade hundreds of thousands of dollars, if not millions, have been more than wasted by the substitution of motor-drives for belt drives. Such a change has often been advantageous, of course, and is occasionally recommended to his clients by the writer: the trouble has been that the enormous investments of electrical manufacturing establishments have forced the electrical salesman more than any other to create a demand for his product, so that not only has he allowed his enthusiasm to run away with him, but he frequently has recommended his product against his own biased judgment; persuading the incompetent shop manager or superintendent to accept his product as a remedy for a small output that is in reality due to a complication of causes that could be cured only by the application of a number of remedial measures.

6 The writer believes, however, that a reaction against this indiscriminate electrification of machine shops has already set in, aside from the influence of the industrial depression, and that the electric drive will be installed, in the near future, only when conditions make it unquestionably more advantageous than the belt-drive.

7 As touched upon by Mr. Van Derhoef, the elastic properties of transmission-rope are probably similar to those of leather belts, and it seems to be in order for someone to ascertain them by the necessary experiments, and subsequently to apply this knowledge by use of the writer's methods.

8 The writer values Mr. Allen's statements of the advantages derived from the adoption of the Taylor system, as introduced by the author in the Yale & Towne Mfg. Co., plant where 4800 belts are thus taken care of. Mr. Allen, in conjunction with Messrs. Taylor, Hathaway and Waldron, has thus supplemented the scant attention paid in the paper to the aspect of the subject most practically important. The reason for this omission is that in his work with belting the writer has derived by far the greatest personal satisfaction from the solution of the mathematical problems involved, and he has been unable to eliminate entirely the personal interest.

9 It is not possible to answer here Mr. Cary's question as to how to estimate the horse-power required to drive each machine in a large plant, but the writer will be pleased to give him, and anybody else interested enough to pay a visit to Philadelphia, an idea of how it is done, by means of slide-rules especially constructed for the purpose.

10 As a further answer to Professor Bird's various statements and questions, the writer will only say that on a more careful reading of the paper, as well as the Appendix, and the copy of the Supplement sent him, he will find most of them answered. For instance, the most valuable mathematical developments in the Appendix and Supplement answer the question why the sum of the tensions of a belt increases with the load; and study of this will help him to formulate for himself an answer to his non-mathematical questioners.

11 As to the effect of crowning a small pulley, the writer heartily agrees with Professor Bird in a general way, though surprised to note with what confidence the latter estimates in the crudest and most superficial way the difference between the tensions in the middle and edge-fibers of a belt running over such a pulley. The writer would not attempt this without taking at least a week's vacation for the purpose, and so far has not felt warranted to do so, though well aware of the existence of the problem.

12 The writer is also highly pleased with the appreciation of his work expressed by Professor Breckenridge and Professor Aldrich, though he has not found the time to enter fully into the latter's second attempt to eliminate the coefficient of friction and the arc of contact in the solution of belt problems.

13 The author is sorry that the considerable trouble to which Mr. Nagle has gone to make comparisons with his own earlier formulae for the horse-power transmitted by leather belting, is based on a misunderstanding of the fundamental basis of the author's work.

14 As stated in the paper, the author bases his figures on a certain tension per square inch of belt, independent both of the strength of the belt itself and its thickness, and of the strength of the lacing, except that the latter must be in excess of the maximum tension brought to bear on a belt while delivering power. The author, therefore, makes no distinction between a single and a double belt, but merely considers the tension per square inch of section, as it has not been definitely proven that the coefficient of friction depends materially on the area of the surface presented by the belt against the pulley.

15 As Mr. Nagle somehow has assumed that the two horse-power curves in Fig. 3 are meant respectively for a single and a double belt, whereas they stand for something totally different, it unfortunately follows that the comparisons made by him of his own and the author's ideas as to what power a belt should be counted on to transmit, have completely miscarried.

16 Mr. Nagle says that we cannot decide upon the coefficient of

friction by formula. This is unquestionably so, but it is also true that, having roughly decided, by one means or another, what we wish to count on as the coefficient of friction at any one velocity of a belt, we may to great advantage make an empirical formula to represent a perfectly-graded change of this coefficient with the velocity; and only by so doing can we effect a mathematical solution of the belt problem that is an improvement on the unquestionably wrong assumption of a coefficient independent of the velocity of the belt, such as 0.42, originally recommended by Mr. Towne, or 0.28, recommended by the late Professor Ruleaux.

17 The author fully agrees with Mr. Nagle that "a new belt on an iron pulley may not have a coefficient of friction of as much as 0.25, while the same belt, well worn and well groomed, will give 0.65 in a clean, dry room;" and, more than that, knows that this elusive quantity will vary all the way from almost 0 to 1.50. However, just because the author is a practical and practicing engineer though very fond of a little pure mathematics in the handling of practical engineering problems, he has adopted *something* as a standard, this something being a variable lying happily between the great extremes, instead of being merely a single average between the extreme values.

18 The author is not at all disappointed because a perfectly new belt will not give the output required, at its minimum tension, without the resort to a temporary application of some good adhesion-producing belt-dressing; nor on the other hand, when a "well worn and groomed" belt at times is capable of giving the output required, at a little less initial tension than the one he aims at maintaining by the means more fully described in the discussions submitted by Mr. Allen and Mr. Hathaway.

19 Mr. Nagle also remarks that we rarely know the exact power to be transmitted except in the case of prime movers, which no doubt is true, so far as the work of most engineers is concerned. However, in the author's practice at least, the maximum output of every belt put up on any machine is known; simply because he personally sets the limit, and has means of seeing that the same is never exceeded.

20 Mr. Nagle refers to his paper read in 1881 as the first one to recognize the effect of centrifugal force in a belt. A correct formula, however, for the loss of effective tension in a belt, due to its centrifugal force, was given by Weisbach, at a much earlier date. This fact does not detract, of course, from the value of Mr. Nagle's paper, in which, probably for the first time, this matter was presented in a manner that made it readily available to the busy, practical engineer.

21 As regards Mr. Nagle's suggestion that the data have not been presented in a sufficiently handy form for the busy engineer, the author believes he has failed to appreciate the slide-rule illustrated in Fig. 5, which contains these data in a form which for handiness leaves tables and diagrams far behind.

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EMPLOYMENT BULLETIN

The Society has always considered it a special obligation and pleasant duty to be the medium of securing better positions for its members. The Secretary gives this his personal attention and is most anxious to receive requests both for positions and for men available. Notices are not repeated except upon special request. Copy for notices in this Bulletin should be received before the 15th of the month. The list of men available is made up of members of the Society and these are on file, with the names of other good men not members of the Society, who are capable of filling responsible positions. Information will be sent upon application.

POSITIONS AVAILABLE

047 Instructorship in kinematics of machinery in Eastern college; incumbent to give lecture and recitation course and parallel drafting room course in the subject. Technical graduate who has shown excellent proficiency in the subject as a student and who has had at least one year of practical experience since graduation desired. New York State.

048 Assistant Professor in steam engine and boiler design; also some work in steam turbine design. Man is desired who has had experience in design and testing, preferably some teaching experience. Salary $1800 to $2000. Location New York State.

049 Wanted—An Assistant Superintendent in factory manufacturing—Location, Pennsylvania.

050 Expert on structural steel as applied to naval turrets or similar work. U. S. Government. Salary $1600 to $1800.

051 Electrical draftsman with experience in application of electrical machinery to naval turrets or similar work. U. S. Government. Salary $1600 to $1800.

052 Eight mechanical draftsmen, preferably experienced in design of ordnance. U. S. Government. Salary $1600 to $1800.

053 Ambitious young man, one with selling experience preferred, to handle in Philadelphia and neighboring towns, a machine involving the installation of complete power plants. A capable man can make this a profitable position.

054 By publisher in New York, young engineer to compile and edit engineering data. Preferably one with editorial experience who can read French and German. Permanent position.

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MEN AVAILABLE

222 Machine shop superintendent or manager. Technical graduate. Experience covers from draftsman and salesman to works manager. All-round executive and mechanic. Successful in handling men and equipment for profitable output. Desires position as superintendent or manager, preferably with company employing 500 men or less.

223 Associate member, aged 30, who has specialized on fuel economy, and is carrying on a consulting practice with headquarters in New York, desires to become associated with other consulting engineer or firm of consulting engineers, either electrical or mechanical, with offices in New York City.

224 Associate desires to make a change. Varied drawing-room experience, including checking and charge of men. Would prefer work on heavy machinery and furnaces for rolling steel or tube mills.

225 Junior member; four years shop experience in design and construction of steam engines and general machinery, three years in charge of drafting departments; past five years designing and supervising construction of steam, gas and hydro-electric power plants; has also had experience in operation of electric plants.

226 Junior, technical graduate, American, 5 years experience in mechanical power station equipment, at present located in Germany, would consider position as European representative, preferably in Germany or England, for engineering or manufacturing company. Speaks German fluently.

227 Member of the Society, now assistant works manager of one of the large manufacturing establishments of the country, will undertake the betterment of existing manufacturing properties, or will develop new ones.

228 Member, with wide experience as executive officer in management of machine tool business, desires similar position. Location New England or New York.

229 Member, Stevens graduate, 25 years experience. Expert on highest grade of interchangeable manufacture. Competent as manager, superintendent, or chief engineer. Experience embraces the manufacture of automobiles, typesetting machinery, typewriters, firearms, etc.

230 Member, twenty years practical experience in designing, manufacturing and marketing special machinery (plant equipments). Broad acquaintance in the East. Will consider proposal from reliable manufacturer, to act as representative. Bank reference.

CHANGES IN MEMBERSHIP

CHANGES OF ADDRESS

ADAMS, Thomas D. (Junior, 1906), Werner and Pfleiderer, and *for mail,* 732 Jefferson Ave., Saginaw, Mich.

AHRNKE, H. P. (Junior, 1902), Pa. Tunnel and Terminal R. R. Co., Office of Ch. Engr. of Elec. Traction, 8–10 Bridge St., New York, N. Y.

ALLEN, George L., Jr. (Junior, 1906), Iloilo, Philippine Islands.

ANDERSON, Harry Warfield (Associate, 1907), V. P., W. E. Austin Co., Mgr., Auto Dept., Atlanta Buggy Co., 1228 Candler Bldg., and *for mail,* No. 6, Lenox Apt., 31 Porter Pl., Atlanta, Ga.

BARROWS, Lee Earle (Junior, 1908), care of Y. M. C. A., Nelsonville, O.

BATCHELOR, Charles (1880), 33 W. 25th St., New York, N. Y.

BLACK, Edward S. (1903), 35 Wade Bldg., Cleveland, O.

BOGARDUS, Henry A. (Associate, 1907), Henry A. Bogardus & Co., 178 E. Huron St., Chicago, Ill.

BRINTON, Willard C. (Junior, 1907), Industrial Engr., Westinghouse Elec. and Mfg. Co., East Pittsburg, and *for mail,* 611 Whitney Ave., Wilkinsburg Sta., Pittsburg, Pa.

CALDWELL, John A. (1907), 90 West St., New York, N. Y., and *for mail,* 55 Walnut St., Montclair, N. J.

CHAMBERLAIN, George E. (1907), 1614 Fisher Bldg., Chicago, Ill.

CHAPMAN, David Albert (Junior, 1908), Supt. of Estate of E. S. Converse Co., 101 Milk St., Boston, and *for mail,* 163 Grover Ave., Winthrop Highlands, Boston, Mass.

CHRISTIE, Alexander G. (Associate, 1907), Research Asst. in Steam Engrg., Univ. of Wisconsin, and *for mail,* 1713 Monroe St., Madison, Wis.

CHURCHILL, Chas. O. (1906), The Georgian Mfg. Co., Binghamton, N. Y.

COMLY, Geo. N. (1880), 1816 W. Genesee St., Syracuse, N. Y.

COON, Thurlow Emmett (Junior, 1908), 1443 Washtenaw Ave., Ann Arbor, Mich.

CRANE, William Edward (1887), 420 Willow St., Waterbury, Conn.

DARLINGTON, Philip J. (1904), The Roto Co., P. O. Box 1043, Hartford, Conn.

DE CAZNOVE, Louis A., Jr. (Junior, 1905), Mech. Engr. of Constr. Dept., E. I. Du Pont De Nemours Powder Co., and *for mail,* The Wilmington, Delaware Ave., Wilmington, Del.

DYER, Robt. M. (1892; 1904), V. P. and Treas., Puget Sound Bridge and Dredging Co., 432–41 Central Bldg., and 420 13th Ave., N., Seattle, Wash.

ESTES, William Wood (1891;1904), Designer, Taft-Pierce Co., Woonsocket, and *for mail,* 245 Waterman St., Providence, R. I.

FLORY, Burton P. (1906), Supt. M. P., Ontario & Western Ry. Co., Middletown, N. Y.

FOX, Royal E., Jr. (Junior, 1901), V. P., The Engineer Co., 30 Church St., Room 1180, and Irving Arms, 222 Riverside Drive, New York, N. Y.

GANNETT, Herbert I. (Junior, 1900), V. P. and Genl. Mgr., Monarch Acetylene Co., 66–70 Exchange St., and 113 Summit Ave., Buffalo, N. Y.

GAZZAM, Joseph P. (1902), Life Member, 5027 Westminster Pl., St. Louis, Mo.

GODFREY, Eli S. (1891), Tannersville, N. Y.

GORDON, Fred. W. (1880), Gladstone, 11th and Pine Sts., Philadelphia, Pa.

GRAVER, Alexander M. (Junior, 1908), Mech. Engr., Wm. Graver Tank Wks., East Chicago, Ind., and 7211 Yale Ave., Chicago, Ill.

GRAY, John Lamont (Associate, 1904), Gray Bros., Engrs. and Shipbuilders, and *for mail*, care of Ardlamont, 9 Esplanade, Williamstown, Melbourne, Victoria, Australia.

HANEY, James Briggs (Junior, 1905), U. S. Engr. Office, McCandless Bldg., Honolulu, Hawaii.

HANSELL, William H. (1908), Member firm of Edward Smith Co., Cons. Engrs., 605 Provident Bldg., and *for mail*, 4420 Sansom St., Philadelphia, Pa.

HAUGHTON, Frank A. (1903), 243 Jamaica Ave., Flushing, L. I., N. Y.

HAYWARD, Henry S., Jr. (1900; 1907), 60 North Ave., Elizabeth, N. J.

HENES, Louis G. (Junior, 1903), Key Route Hotel, Oakland, Cal.

HERBERT, Charles G. (1900), Solvay Process Co., Syracuse, N. Y.

HIRT, Louis Joseph (1894), Mech. Engr., Broad Exchange Bldg., 25 Broad St., New York, and *for mail*, 34 Morsemere Pl., Yonkers, N. Y.

HUMPHREYS, Alex. C. (1884), Manager, 1907–1910, Life Member; Pres., Stevens Inst. of Tech., Hoboken, N. J., Pres., Buffalo Gas Co., and Senior Member of Humphreys & Glasgow, Incorp., 165 Broadway, New York, N. Y.

JACKSON, Roscoe B. (Junior, 1904), 1091 Champlain St., Detroit, Mich.

JAKOBSSON, Herman G. (1907), Engrg. Dept., Midvale Steel Co., Philadelphia, Pa.

LARSON, Charles J. (1907), Ch. Engr., Union Elec. Co., and *for mail*, 1058 Locust St., Dubuque, Ia.

LEEPER, Ralph W. (Junior, 1908), 304 Clinton St., Schenectady, N. Y.

LILLIE, Grant W. (Junior, 1901), Mech. Engr., St. Louis & San Francisco R. R., and *for mail*, 1120 Summit St., Springfield, Mo.

LUCAS, Henry van Noye, Jr. (Junior, 1905), present address unknown.

LUNGER, Waldo G. (Junior, 1901), 637 Hinman Ave., Evanston, Ill.

McKIEVER, Wm. Henry (1900), Everett Bldg., Union Sq. N., and *for mail*, 120 Central Park S., New York, N. Y.

NEUHAUS, Fritz A. E. (1898;1906), Ch. Engr. and Genl. Supt., A. Bosrig, Tegel Berlin, and Olivaerplatz 7, Charlottenburg, Germany.

PALMER, Virgil Maro (Junior, 1905), Selden Motor Vehicle Co., Rochester, N. Y.

PERRIGO, Oscar Eugene (1904), Cons. Mech. Engr. and Pres., Modern Systems Cor. School, 6 Beacon St., Boston, and 151 Lynnfield St., Peabody, Mass.

PERRY, Samuel B. (Junior, 1895), 72 William St., New York, and Hollis, L. I., N. Y.

PINGER, Geo. C. (Junior, 1907), The Wm. Tod Co., and *for mail*, 239 Spring St., Youngstown, O.

POWELL, E. Burnley (Junior, 1904), Stone & Webster Engrg. Corp., 147 Milk St., Boston, Mass.

PRATT, Charles Richardson (1896), Cons. Engr., 1123 Broadway, New York, N. Y., and 39 Gates Ave., Montclair, N. J.

RIDDLE, Howard Sterling (1905), Wks. Engr., The Jeffrey Mfg. Co., and *for mail*, 904 Neil Ave., Columbus, O.

ROBERTS, Edmund W. (1904), Mech. Engr., V. P. and Genl. Mgr., The Roberts Motor Co., Sandusky, O.

ROSE, William Holliday (Junior, 1901), 220 Broadway, New York, N. Y.

ROSS, Taylor W. (Junior, 1895), Asst. Supt. of Hull Constr., Newport News Ship-Building and Dry Dock Co., and *for mail*, 3112 West Ave., Newport News, Va.

RUST, Edwin Gray (1901), Treas., Sheffield Coal and Iron Co., Sheffield, Ala.

SARENGAPANI, T. S. (Junior, 1903), Head Draftsman, P. W. D., Bezwada, and *for mail*, Karantattamkudy, Tanjore, Madras, India.

SMITH, William E. (Junior, 1908), 518 Olive St., Scranton, Pa.

TALCOTT, R. Barnard (1907), Florence Court, Washington, D. C.

TRACY, Theron H. (1902), Pres., Tracy-Devereaux Co., 211-15 Kerckhoff Bldg., Los Angeles, Cal.

VAN VALKENBURGH, Ralph D. (1901; Associate, 1905), Ch. Engr., H. W. Caldwell & Son Co., Western Ave., 17-18th Sts., and *for mail*, 1088 Millard Ave., Chicago, Ill.

WEAR, Burt C. (Junior, 1905), Draftsman, Engrg. Dept., Republic Iron and Steel Co., and *for mail*, 272 Arlington St., Youngstown, O.

WILDER, Sylvanus Wells (Junior, 1907), Supt., Dolphin Jute Mills, and *for mail*, 283 Ellison St., Paterson, N. J.

WILSON, Clarence C. (Junior, 1900), Cons. Engr., 22 First St., San Francisco, Cal.

ZIMMERMAN, Oliver B. (1905), Ch. Draftsman, M. Rumely Co., La Porte, Ind.

NEW MEMBERS

ALDEN, Herbert W. (1908), Mech. Engr., Timken Roller Bearing Axle Co., Canton, O.

BANNON, Leo Matthew (Junior, 1908), Asst. Supt., Union Bleaching and Finishing Co., Greenville, S. C.

BIXBY, William P. (Junior, 1908), Erie Railroad Co., and *for mail*, P. O. Box 364, Meadville, Pa.

CHESTER, Chas. Porter (Associate, 1908), Supt., The Morenci Water Co., Morenci, Ariz.

CHURCH, Elihu C. (Junior, 1908), Lecturer, Dept. of C. E., Columbia Univ., and *for mail*, 4 E. 130th St., New York, N. Y.

CRAIG, Charles H., Jr. (1908), Asst. Supt., Am. Steam Gage and Valve Mfg. Co., 208 Camden St., Boston, and *for mail*, Needham, Mass.

DE VED, Horace W. (Junior, 1908), Asst. to Engr., Westchester Lighting Co., Mt. Vernon, N. Y.

DULL, Raymond Wm. (1908), Ch. Engr., Stephens-Adamson Mfg. Co., Aurora, Ill.

DUNHAM, George W. (1908), Ch. Engr., Olds Motor Wks., and 738 Ionia St. W., Lansing, Mich.

DYER, Robert A., Jr. (1908), Asst. Genl. Mgr., Rochester, Syracuse & Eastern R. R. Co., and *for mail*, 2 Sheridan St., Auburn, N. Y.

ENGLISH, Harry K. (Associate, 1908), Box 688, Gary, Ind.

KEIL, Gustave B. (1908), M. M., Mills Novelty Co., Mills Bldg., and *for mail,* 2340 N. Paulina St., Chicago, Ill.

MEES, Curtis A. (Associate, 1908), Designing Engr., Southern Power Co., Charlotte, N. C.

NEELY, Frank Henry (Junior, 1908), Westinghouse Elec. and Mfg. Co., and *for mail,* 435 Ross Ave., Wilkinsburg, Pa.

PARKER, Levin S. (1908), Mech. Engr., Atlantic Gulf and Pacific Co., 2407 Park Row Bldg., New York, N. Y.

PAUL, Charles Edward (1908), Assoc. Prof. of Mechanics, Armour Inst. of Tech., and *for mail,* 6355 Ingleside Ave., Chicago, Ill.

PULMAN, Thomas Chas. (1908), 10 Clive St., Calcutta, India.

ROBINSON, Arthur L. (1908), Elec. Engr., Isthmian Canal Com., Culebra, Canal Zone, Central America.

SATTERFIELD, Howard E. (Associate, 1908), The N. C. College of Agriculture and Mechanic Arts, West Raleigh, N. C.

SCOTT, Arthur Curtis (1908), Prof. of Elec. Engrg., Univ. of Texas, Austin, Texas.

SPENCER, Frank C. (Associate, 1908), Mech. and Constructing Engr., 7135 Eggleston Ave., Chicago, Ill.

THOMAS, Carl C. (1908), Prof. of Mech. Engrg., Univ. of Wisconsin, Madison, Wis.

THOMPSON, Byron Lyman (Associate, 1908), Asst. Mgr., Bi-Carbonate Dept., Solvay Process Co., and *for mail,* 212 Erie St., Syracuse, N. Y.

TOMLINSON, Charles E. (Associate, 1908), Smith Premier Typewriter Co., Syracuse, N. Y.

VOIGHT, Henry Gustave (1908), Supt. of Design and Constr., Russell & Erwin Mfg. Co., and *for mail,* P. O. Box 406, New Britain, Conn.

WALLACE, Jacob H. (Associate, 1908), Instr. in drawing, Univ. of Colo., and *for mail,* 1313 7th St., Boulder, Colo.

WALLICHS, Adolph O. (1908), Prof., Technische Hochschule, and *for mail* Wizze-Allee 65, Aachen, Germany.

WINSHIP, Walter E. (1908), Advisory Engr., Gould Coupler Co., Sales Engr., Gould Storage Battery Co., and *for mail,* 82 W. Washington Pl., New York, N. Y.

PROMOTIONS

COX, Frank G. (1905; 1908), Engr. Otis Elevator Co., 17 Battery Pl., New York, N. Y.

LIBBEY, Joseph Harold (1901; 1904; 1908), Mech. and Elec. Engr., Stone & Webster Engrg. Corp., 147 Milk St., Boston, and 14 Parsons St., West Newton, Mass.

OHLE, Ernest L. (1906; 1908), Washington Univ., St. Louis, Mo.

O'NEIL, Frederick Wm. (1901; 1908), N. Y. Mgr., Nordberg Mfg. Co., Room 1009, 42 Broadway, New York, and 260 Pelham Rd., New Rochelle, N. Y.

WILLCOX, George B. (1895; 1908), Secy. Treas., and Genl. Mgr., Willcox Engrg. Co., 502 Eddy Bldg., and 1413 Genesee Ave., Saginaw, Mich.

RESIGNATIONS

FOUCARD, Marcel L. NORTHRUP, Lewis M.
WHITLOCK, R. H.

DEATHS

ALLEN, Walter M.
CHICKERING, Kenton
GRAY, Thomas
HUYETTE, William S.

Gas Power Section

CHANGES OF ADDRESS

COMLY, Geo. N. (1908), 1816 W. Genesee St., Syracuse, N. Y.
LANE, J. S. (1908), 50 Church St., New York, N. Y.
ZIMMERMAN, Oliver B. (1908), Ch. Draftsman, M. Rumely Co., La Porte, Ind.

NEW MEMBERS

BAKER, John A. (Affiliate, 1908), Traveling Engr., Power and Mining Mchy. Co., 115 Broadway, New York, N. Y.
BARNABY, Charles W. (1908), 309 Broadway, New York, N. Y.
BUMP, Milan Raynard (Affiliate, 1908), Secy., Doherty Operating Co., 60 Wall St., New York, N. Y.
COOK, Wm. Pierson, Jr. (Affiliate, 1908), Salesman, Buick Motor Co., 1111 Dean St., Brooklyn, N. Y.
CORMACK, George, Jr. (Affiliate, 1908), V. P. and Designer, Rockford Eng. Wks., Rockford, Ill.
ENNIS, Wm. Duane (1908), Prof. Mech. Engrg., Polytechnic Inst., Brooklyn, N. Y.
GILLETTE, Ralph P. (Affiliate, 1908), Mgr. Mech. Sales and Secy., Minneapolis Steel and Mchy. Co., Minneapolis, Minn.
HANSON, George (Affiliate, 1908), Supt., Charter Gas Eng. Co., Sterling, Ill.
HASBROUCK, Stephen A. (Affiliate, 1908), Mech. Engr., 177 Willetts ave., New London, Conn.
HOPCROFT, Ernest Bigly (Affiliate, 1908), 511 Insurance Bldg., Rochester, N. Y.
LATHROP, Jay Cowden (Affiliate, 1908), Cons. Engr., 717 Terminal Bldg., New York, N. Y.
LOOMIS, Malcolm F. (Affiliate, 1908), Sales Mgr. and Supt., Alamo Mfg. Co., Hillsdale, Mich.
MAIBAUM, Jerome (Affiliate, 1908), Leading Elec. Draftsman, N. Y. Edison Co., 55 Duane St., and 1052 Grant Ave., New York, N. Y.
MATTHEWS, Fred E. (1908), Room 901, 90 West St., New York, N. Y.
MAYERS, J. Alex (Affiliate, 1908), Gas Engr., 56 Pine St., New York, N. Y.
MONAHAN, Louis J. (Affiliate, 1908), V. P., Supt. and Mech. Engr., Termaat & Monahan Co., 270 Washington St., Oshkosh, Wis.
MORRISON, William S. (Affiliate, 1908), Leading Mech. Draftsman, N. Y. Edison Co., 55 Duane St., New York, N. Y.

NILSON, Lars G. (Affiliate, 1908), Ch. Engr., Strang Gas-Elec. Car Co., and *for mail,* 108 13th St., Hoboken, N. J.

OESTERREICHER, Sandor Ignatius (Affiliate, 1908), Elec. Draftsman, 342 High St., Newark, N. J.

PARKER, John Castlereagh (1908), Mech. and Elec. Engr., Rochester Ry. and Light Co., Rochester, N. Y.

PLATTS, C. Arthur (Affiliate, 1908), Ch. Engr. Producer Gas Sta., B. E. Ry. Co., 399 Salem St., Medford, Mass.

SANDELL, Sixten O. (Affiliate, 1908), Draftsman, N. Y. Edison Co., 55 Duane St, New York, N. Y.

SEAGER, James B. (1908), Genl. Mgr., Olds Gas Power Co., Lansing, Mich.

SERGEANT, Chas. H. (1908), Mech. Engr., 4 Manhattan Ave., New York, N. Y.

SKEHAN, Eugene A. (Affiliate, 1908), Leading Elec. Draftsman, N. Y. Edison Co., 55 Duane St., New York, N. Y.

SMITH, Bronson H. (Affiliate, 1908), Mech. Engr., Westinghouse, Church, Kerr & Co., New York, and *for mail,* 450 E. 21st St., Brooklyn, N. Y.

SNYDER, William E. (1908), Mech. Engr., Am. Steel and Wire Co., Frick Bldg., Pittsburg, and *for mail,* Denslow Apts., California Ave., Allegheny, Pa.

SPARROW, Ernest P. (1908), B. F. Sturtevant Co., Hyde Park, and *for mail,* 18 Gleason St., New Dorchester, Mass.

STETSON, George R. (1908), Pres. and Genl. Mgr., New Bedford Gas and Edison Light Co., 125 Middle St., and 7 Anthony St., New Bedford, Mass.

YOUNG, Nelson J. (Affiliate, 1908), N. Y. Edison Co., 55 Duane St., New York, N. Y.

COMING MEETINGS

AERONAUTIC SOCIETY
March 10, etc., evenings, weekly meetings, Automobile Club of America, W. 54th St., New York. Secy., Wilbur R. Kimball.

AMERICAN GAS POWER SOCIETY
April 27, quarterly meeting, Minneapolis, Minn. Secy., R. P. Gillette.

AMERICAN GEOGRAPHICAL SOCIETY
March 23, 29 W. 39th St., New York, 8 p.m. Paper: Across Widest Africa, A. H. S. Landor. Clerk, H. D. Ralph.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
March 12, April 9, 33 W. 39th St., New York, 8 p.m. Secy., R. W. Pope.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
March 26, monthly meeting, Toronto Section. Secy. *pro tem.*, W. H. Eisenheis, 1207 Traders' Bank Bldg.

AMERICAN SOCIETY OF CIVIL ENGINEERS
March 17, April 7, 220 W. 57th St., New York. Secy., C. W. Hunt.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS
March, 24, joint meeting on Conservation of Natural Resources, 29 W. 39th St., New York, 8 p.m. Secy., Calvin W. Rice.

AMERICAN RAILWAY ENGINEERING AND MAINTENANCE OF WAY ASSOCIATION
March 16–18, annual convention, Auditorium Hotel, Chicago, Ill. Secy., E. H. Fritch, 962 Monadnock Blk.

ARCHITECTURAL INSTITUTE OF CANADA
April 6, Special General Meeting, Toronto, Ont. Secy., Alcide Chaussé, Montreal, Que.

ASSOCIATION OF ELECTRIC LIGHTING ENGINEERS OF NEW ENGLAND
March 17, annual meeting, Boston, Mass.

BLUE ROOM ENGINEERING SOCIETY
April 1, 29 West 39th St., New York. Secy., W. D. Sprague.

BOSTON SOCIETY OF ARCHITECTS
April 6. Secy., Edwin J. Lewis, 9 Park St.

BOSTON SOCIETY OF CIVIL ENGINEERS
March 17, annual meeting, Tremont Temple. Secy., S. E. Tinkham, City Hall.

BROOKLYN ENGINEERS' CLUB
March 11, 197 Montague St., Brooklyn, N. Y. Paper: Fire Hazard and Fire Protection in the U. S., Hugh T. Wreaks. Secy., J. Strachan.

CANADIAN CEMENT AND CONCRETE ASSOCIATION
March 1–6, Convention, Toronto, Ont. Secy., A. E. Uren, 62 Church St.

CANADIAN FREIGHT ASSOCIATION
April 9, annual meeting. Secy., T. Marshall, Toronto, Ont.

CANADIAN MINING INSTITUTE
March 3–5, annual meeting, Windsor Hotel, Montreal, Que. Secy., H. Mortimer-Lamb. Windsor Hotel.

CANADIAN RAILWAY CLUB
April 6, Windsor Hotel, Montreal, Que., 8 p.m. Secy., Jas. Powell, St. Lambert, Montreal.

CANADIAN SOCIETY OF CIVIL ENGINEERS
March 12, General Sectional Meeting; March 19, electrical section; March 26, mechanical section; April 2, mining section. 413 Dorchester St. W., Montreal, Que. Secy., Prof. C. H. McLeod.

CANADIAN SOCIETY OF CIVIL ENGINEERS, Manitoba Branch
March 4, April 8, monthly meetings, University of Manitoba. Paper for March: Transcontinental Railway from Moncton to Winnipeg, S. R. Poulin. Secy., E. Brydone Jack.

CANADIAN SOCIETY OF CIVIL ENGINEERS, Toronto Branch
March 25, regular meeting, 96 King St. W. Secy., T. C. Irving, Jr.

CAR FOREMEN'S ASSOCIATION OF CHICAGO
April 12. Secy., Aaron Kline, 326 N. 50th St.

CENTRAL ASSOCIATION OF RAILROAD OFFICERS
April 13, Cincinnati, Ill., 11 a.m.

CENTRAL ASSOCIATION OF RAILROAD OFFICERS
March 11, Toledo, O. Secy., H. M. Ellert.

CENTRAL RAILWAY AND ENGINEERING CLUB OF CANADA
March 16, Rossin House, Toronto, Ont. Secy., C. L. Worth, Room 409, Union Sta.

CENTRAL RAILWAY CLUB
March 12, Hotel Iroquois, Buffalo, N. Y., 8 p.m. Paper: The Use of Steel in Passenger Car Construction, J. McE. Ames. Secy., H. D. Vought, 95 Liberty St., N. Y.

CLEVELAND ENGINEERING SOCIETY
March 9, monthly meeting, Caxton Building. Paper: Niagara Falls Hydraulic Power Co., G. R. Shepherd. Secy., Joe C. Beardsley.

COLORADO SCIENTIFIC SOCIETY
April 3, monthly meeting, Denver. Secy., Dr. W. A. Johnston, 801 Symes Bldg.

EASTERN ASSOCIATION CAR SERVICE OFFICERS OF NEW YORK
March 25.

ENGINEERING ASSOCIATION OF THE SOUTH
March 16, monthly meeting, Nashville Section, Carnegie Library Bldg. Section Secy., H. H. Trabue, Berry Blk., Nashville.

ENGINEERING SOCIETY OF THE STATE UNIVERSITY OF IOWA
April 6, monthly meeting, Iowa City, Ia. Secy., Dean Wm. G. Raymond.

ENGINEERS' AND ARCHITECTS' CLUB
March 15, 303 Norton Bldg., Louisville, Ky. Secy., Pierce Butler.

ENGINEERS' CLUB OF BALTIMORE
April 3, monthly meeting. Secy., R. K. Compton, City Hall.

ENGINEERS' CLUB OF CENTRAL PENNSYLVANIA
April 6, monthly meeting, Gilbert Bldg., Harrisburg. Secy., E. R. Dasher.

ENGINEERS' CLUB OF CINCINNATI
March 18, 25 E. 8th St. Secy., E. A. Gast, P. O. Box 333.

ENGINEERS' CLUB OF PHILADELPHIA
March 20, April 3, 10, 1317 Spruce St. Secy., H. G. Perring.

ENGINEERS' CLUB OF TORONTO
March 11, etc., weekly, 96 King St., W., Toronto, Ont. Secy., R. B. Wolsey.

ENGINEERS' SOCIETY OF MILWAUKEE
March 10, 456 Broadway, Milwaukee, Wis. Secy., W. Fay Martin.

ENGINEERS' SOCIETY OF WESTERN PENNSYLVANIA
March 16, regular meeting; April 6, Sectional Meeting. Secy., E. K. Hiles.

EXPLORERS' CLUB
April 2, 29 West 39th St., New York. Secy., H. C. Walsh.

FRANKLIN INSTITUTE
March 11, Philadelphia, Pa. Paper: Power Factor and Commutation Conditions in Singlephase Series Motors, A. S. McAllister.

GENERAL MANAGERS ASSOCIATION OF CHICAGO
March 18.

GENERAL SUPERINTENDENTS' ASSOCIATION OF CHICAGO
March 17. Secy., H. D. Judson, 209 Adams St.

ILLUMINATING ENGINEERING SOCIETY
March 11, April 8, monthly meetings, New York Section, 29 W. 39th St., 8 p.m. Secy., P. S. Millar.

INTERNATIONAL MASTER BOILER-MAKERS' ASSOCIATION
April 27–30, Convention, Hotel Sealbach, Louisville, Ky. Secy., H. D. Vought, 95 Liberty St., New York. Standardizing Blue Prints for Building Boilers; Boiler Explosions; Best Method of Applying Flues, Best Method for Caring for Flues While Engine is on the Road and at Terminals and Best Tools for Same; Flexible Staybolts Compared with Rigid Bolts; Best Method of Applying and Testing Same; Steel vs. Iron Flues, What Advantage and What Success in Welding Them; Best Method of Applying Arch Brick; Standardizing of Shop Tools; Standardizing of Pipe Flanges for Boilers and Templets for Drilling Same; Which is the long way of the Sheet; Best Method of Staying the Front Portion of Crown Sheet on Radial Top Boiler to Prevent Cracking of Flue Sheet in Top Flange; Rules and Formulas; Senate Bill.

IOWA ELECTRICAL ASSOCIATION
April 21, 22, Cedar Rapids. Secy., W. N. Keiser, Des Moines.

IOWA RAILWAY CLUB
March 12, April 9, Des Moines.

LOUISIANA ENGINEERING SOCIETY
April 12, 323 Hibernia Bldg., New Orleans. Secy., L. C. Datz.

MASSACHUSETTS STREET RAILWAY ASSOCIATION
March 10, Boston. Secy., Charles S. Clark, 70 Kilby St.

MUNICIPAL ENGINEERS OF THE CITY OF NEW YORK
March 24, 29 W. 39th St., 8:15 p.m. Secy., C. D. Pollock.

NATIONAL ASSOCIATION OF AUTOMOBILE MANUFACTURERS
April 7, New York. Secy., C. C. Hildebrand, 7 E. 42d St.

NEW ENGLAND RAILROAD CLUB
March 9, annual meeting, Young's Hotel, Boston, Mass., 8 p. m. Secy., Geo. H. Frazier, 10 Oliver St. Paper: The Railroad Club; its Worth, A. W. Martin.

NEW ENGLAND STREET RAILWAY CLUB
March 25, annual meeting, American House, Boston, Mass. Secy., John J. Lane, 12 Pearl St.

NEW ENGLAND WATERWORKS ASSOCIATION
March 10, regular meeting. Secy., Willard Kent, Tremont Temple, Boston, Mass.

NEW YORK RAILROAD CLUB
March 19, 29 W. 39th St., 8.15 p.m. Secy., H. D. Vought, 95 Liberty St.

NEW YORK SOCIETY OF ACCOUNTANTS AND BOOKKEEPERS
March 16, etc., weekly meetings, 29 W. 39th St., 8 p.m. Secy., T. L. Woolhouse.

NEW YORK TELEPHONE SOCIETY
March 16, 29 West 39th St., New York, 8 p.m. Secy., T. H. Laurence.

NORTHERN RAILWAY CLUB
March 27, Commercial Club Rooms, Duluth, Minn. Secy., C. L. Kennedy.

NORTHWEST RAILWAY CLUB
April 13, Minneapolis, Minn. Secy., T. W. Flannagan, Care Soo Line, Minneapolis.

NOVA SCOTIA SOCIETY OF ENGINEERS
March 11, April 8, monthly meetings, Halifax. Secy., S. Fenn.

PROVIDENCE ASSOCIATION OF MECHANICAL ENGINEERS
March 23, monthly meeting, Technical High School Hall, 8 p.m. June 22, annual meeting. Secy., T. M. Phetteplace.

PURDUE MECHANICAL ENGINEERING SOCIETY
March 17, etc., fortnightly meetings, Purdue University, Lafayette, Ind., 6:30 p.m. Secy., L. B. Miller.

RAILWAY CLUB OF KANSAS CITY
March 19.

RAILWAY CLUB OF PITTSBURGH
March 26, monthly meeting, Monongahela House, Pittsburgh, Pa., 8 p.m. Secy., J. D. Conway, Genl. Office, P.&.L.E.R.R.

RAILWAY SIGNAL ASSOCIATION
March 15, Chicago, Ill.

RENSSELAER SOCIETY OF ENGINEERS
March 12, etc., fortnightly meetings, 257 Broadway, Troy, N. Y. Secy., R. S. Furber.

ROAD AND TRACK SUPPLY ASSOCIATION
March 15–20, Exhibition, Coliseum, Chicago, Ill. Secy., John N. Reynolds, 160 Harrison St.

ROCHESTER ENGINEERING SOCIETY
March 12, April 9, monthly meetings. Secy., John F. Skinner, 54 City Hall.

ST. LOUIS RAILWAY CLUB
March 12, monthly meeting, Southern Hotel, 8 p.m. Paper: Piece Work in the Repair Shop, D. T. Taylor. Secy., B. W. Frauenthal.

SCRANTON ENGINEERS' CLUB
March 18, Board of Trade Bldg. Secy., A. B. Dunning.

TECHNICAL SOCIETY OF BROOKLYN
March 19, April 2, semi-monthly meetings, Arion Hall, Arion Pl., Brooklyn, N. Y., 8:30 p.m. Pres., M. C. Budell, 20 Nassau St., New York.

TECHNICAL SOCIETY OF THE PACIFIC COAST

April 2, San Francisco, Cal., Secy., Otto von Geldern, 1978 Bdwy.

TECHNOLOGY CLUB OF SYRACUSE

April 13, monthly meeting, 502 Bastable Blk., 8 p.m. Secy., Robert L. Allen.

WESTERN RAILWAY CLUB

March 16, monthly meeting, Auditorium Hotel, Chicago, Ill., 8 p.m. Secy., Jos. W. Taylor, 390 Old Colony Bldg.

WESTERN SOCIETY OF ENGINEERS

April 7, regular meeting. Paper: Reconstruction of the Street Car Tracks in Chicago, Geo. Weston. April 9, electrical section. Secy., J. H. Warder, 1737 Monadnock Blk., Chicago.

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Terms expire at Annual Meeting of 1909

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Henry G. Stott .... New Rochelle, N. Y.

Terms expire at Annual Meeting of 1910

H. L. Gantt .... Pawtucket, R. I.
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Terms expire at Annual Meeting of 1911

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MEETINGS

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L. R. Pomeroy (3)
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Charles E. Lucke (4)
H. de B. Parsons (5)

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H. W. Spangler (4)
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Note.—Numbers in parentheses indicate length of term in years that the member has yet to serve.

SPECIAL COMMITTEES

1909

On a Standard Tonnage Basis for Refrigeration

D. S. Jacobus — G. T. Voorhees
A. P. Trautwein — Philip De C. Ball
E. F. Miller

On Society History

John E. Sweet — H. H. Suplee
Charles Wallace Hunt

On Affiliated Societies

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R. H. Fernald — H. H. Suplee
F. W. Taylor

On Constitution and By-Laws

Chas. Wallace Hunt, *Chairman* — F. R. Hutton
G. M. Basford — D. S. Jacobus
Jesse M. Smith

On Conservation of Natural Resources

Geo. F. Swain, *Chairman* — L. D. Burlingame
Charles Whiting Baker — M. L. Holman
Calvin W. Rice

On International Standard for Pipe Threads

E. M. Herr, *Chairman* — Geo. M. Bond
William J. Baldwin — Stanley G. Flagg, Jr.

On Thurston Memorial

Alex. C. Humphreys, *Chairman* — Charles Wallace Hunt
R. C. Carpenter — J. W. Lieb, Jr.
Fred J. Miller

On Revision and Extension of the Code for Testing Gas Power Machinery

Charles E. Lucke, *Chairman* — Geo. H. Barrus
E. T. Adams — D. S. Jacobus
Arthur West

On Hudson-Fulton Celebration

Geo. W. Melville — M. L. Holman
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1909

On John Fritz Medal

HENRY R. TOWNE (1) F. R. HUTTON (3)
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On Board of Trustees United Engineering Societies Building

CHAS. WALLACE HUNT (1) F. R. HUTTON (2)
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SECRETARY

Geo. A. Orrok

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